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COMM-Q, A SIMULATION MODEL TO DETERMINE
SATURATION POINTS IN NODAL TYPE NETWORKS

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The objective of this thesis is to develop a simulation model to determine the point at which saturation begins to affect a specific nodal type network and to assess the performance of that network under various loading conditions. The model developed in this research is titled the COMM-Q model. The COMM-Q model represents the MSRT-RAU portion of the US Army's Mobile Subscriber Equipment tactical communications system. The outputs of the COMM-Q model are the generic network performance measures: Link Utilization, Radio Utilization, Saturation Level, and Grade of Service.

The research reveals that network saturation will be a problem for the MSRT portion of the MSE network resulting in a low Grade of Service. The saturation level is highly dependent

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CHAPTER I

INTRODUCTION

Many service networks are based on a "nodal" concept, meaning that the total geographical area in which the service's "customers" reside or operate in, is divided up into smaller geographic areas called nodes. These nodes are then somehow interconnected to form the total service network. Some examples of nodal networks in operation today are communication networks (both civilian and military), computer networks, emergency service facilities such as rescue squads, fire stations, police or hospital area coverage, electric utilities and Strategic Defense Initiative (SDI) missile defensive systems.

This nodal concept has proven to be an excellent method of providing coverage for a large geographical area with a limited or finite number of resources. This is especially important during inflationary periods when a particular level of coverage must be maintained while simultaneously keeping expensive resources at minimum levels adequate to the task. The reason for this is to avoid the servicing organization pricing itself out of business or a municipality exceeding its budget. Of prime importance is that all users in the network have access to, or are serviced by at least one of the nodal resources. Two important examples are computer networks and communications networks. In the case of computer networks, redundant or like processors at

node centers may be able to accomplish the processing that a particular user desires. In a communications network such as a cellular telephone network, the nodes or "cells" are configured to permit a "handoff", that is, a smooth transfer of a call from a channel in one node or cell to a different channel in an adjacent node or cell as the customer moves through the network.

There are two general categories of nodal networks: static networks and dynamic networks. Static networks are predicated on the assumption that demand for service in a particular node will be constant. Dynamic networks are based on the assumption that the pattern of demand for service changes over time. Static networks are rare and as such will not be considered in this thesis.

The majority of networks in existence today are dynamic. For example, when a municipality specifies a fire station's location in a dynamic setting, that municipality must consider the fact that some fire fighting equipment may not be available for an assignment because the equipment is in use at another fire. In a computer network, a particular processor may not be available to a user because it is servicing a demand equal to or of greater priority or all communication links to that processor are busy. In the SDI case, a missile launch site or laser facility may be engaging numerous incoming missiles and is then unavailable to respond to additional requests for service.

Communications networks may yield the most recognizable example of unavailability to the average person; a telephone

switch can quickly become overloaded and is unable to provide service in times of great demand. If the typical telephone system customer has ever tried to call ones mother via long distance on Mothers Day or Christmas Day, the point is clearly illustrated.

This thesis will concentrate on the dynamic nodal system; specifically, it will address the point at which the service of a particular network begins to degrade due to nodal saturation. Nodal saturation is defined as the point when all resources within a particular node are in service and thus cannot service the remaining customers within the node's area of coverage. In other words the demand (rate) exceeds service capacity (rate). In order for the network to provide "coverage" for the remaining customers in the saturated node, neighboring nodes must temporarily extend their boundaries if it is possible for them to do so.

Network managers must understand how the saturation of individual nodes affects their network. For emergency service networks, failure to understand this relationship could cause those services not being able to keep pace with a drastic situation resulting in the loss of human lives. Again, if a communications network services an emergency services facility and that network is not responsive due to nodal saturation, human lives may be lost. If a communications network happens to be providing command and control for a United States Army fighting force on a battlefield and becomes degraded due to node saturation, human lives can be lost. In the case of computer networks the effect may range

from endangerment of human life (e.g., air traffic control systems) to a loss of productivity (local area networks in a business office).

It is the objective of this research to develop a usable model for the following purposes: (1) to determine the point at which nodal saturation begins to effect a network and; (2) to assess the performance of the network under various loading conditions using standard network performance measures.

Unless techniques such as the one described in this research are developed and refined for measuring system performance, networks will be poorly managed and not utilized to their fullest capacity.

The following chapter of the thesis presents an extensive review of the literature applicable to the research including saturation problems in existing networks and the techniques used to solve those problems. This is followed by a chapter which more clearly defines the problem, details the specific network to be modeled and provides the reason as to why this network was chosen. The fourth chapter of this thesis presents the approach taken to solve the stated problem. The fifth chapter presents the results of running the simulation model and an analysis of those results. The last chapter provides conclusions and extensions to the research.

CHAPTER II

LITERATURE REVIEW

As discussed in the introduction, many network systems may be considered as being nodal in nature. The following chapter presents a review of the literature relating to several types of nodal servicing networks and the methods used to evaluate those networks to determine basic levels of performance. The types of networks discussed will be the those associated with: the Strategic Defense Initiative; Emergency Services Facilities; Computer networks; and Communications networks.

Strategic Defense Initiative

The basic intent behind the United States of America's Strategic Defense Initiative (SDI) program is to blanket the country with a series of layers which would form a defensive shield against incoming strategic nuclear missiles. Richard L. Garwin of the Center for Science and International Affairs at Harvard University states that the leading candidate SDI system proposal is currently being evaluated by congressional committee. The proposed system consists of three defensive layers which would provide an eventual defensive effectiveness of ninety percent against the 1996 Soviet force [1].

This proposed system's first layer consists of two thousand satellites carrying eleven thousand space-based kinetic kill vehicles. The mission of these missiles would

be to attack Soviet offensive missiles during their boost and post-boost phases. The second layer consists of ten thousand Exoatmospheric Re-entry Vehicle Interceptor Subsystems (ERIS), which are long-range interceptor missiles which attack incoming missiles in flight. The remaining layer is made up of three thousand High Endoatomspheric Defensive Interceptor (HEDI) missiles. These missiles are non-nuclear missiles whose primary mission is to attack any offensive missiles which make it through the first two layers [2].

Each layer of this defensive shield can be thought of as a node in limited resource system. The system is limited in resources primarily due to the excessive cost of building and implementing the system which is estimated to be $120 billion.

As stated above, each of the three nodes or layers has a particular function in supporting the network to maintain an effective level of coverage, and if one node fails or becomes overloaded (saturated) the remaining nodes must target and defend against any excess offensive missiles making their way through the previous node or nodes. If one of the nodes cannot accomplish its stated mission, the level of protection drops drastically. Therefore, it can be seen that nodal saturation is a severe problem and must be considered for any proposed SDI system. Because of the destructive power of nuclear weapons, millions of Americans would perish if even a few Soviet warheads could penetrate the shield [3].

Clausen and Brower have stated that the greatest threat to the success of SDI is that it could easily be overwhelmed by Soviet decoy warheads, which are expected to be up to 100 for every real warhead. Without a way to distinguish (and thus ignore) the decoys, which in space would follow the same flight path as the warheads, the ERIS and HEDI layers would have to shoot at every detected target. Infrared sensors and radars could be fooled by relatively simple decoys designed to imitate the radar characteristics of actual warheads, or by warheads that imitate decoys [4].

Another inherent hazard to any SDI system is that of system control. Most of the proposed systems currently under research make use of satellites for reconnaissance, launch detection, communications, and battle management. Estimates of the workload on controlling satellites state that there may be the need for re-targeting more than ten times per second during an attack. If the Soviets concentrate their pre-strike offensive efforts on knocking out American SDI system controlling satellites, the effectiveness of one or more of the defensive layers becomes severely degraded [5]. The remaining layer or layers then become saturated and must then accomplish more than they were designed to accomplish.

Emergency Service Facilities

Emergency service facilities are typically defined as dispatching points for ambulances, fire fighting equipment, police or other emergency vehicles. These service facilities can also be thought of as nodal systems. A single

emergency service facility typically has the responsibility to provide coverage for a large geographical area. Therefore the physical location of these facilities within a geographical area is a problem of extreme importance. Many operations research techniques have been applied to solving this location problem with differing degrees of success. Chrissis states that the primary reason for studying this type of problem is to determine the minimum number of facilities required to cover all demand points. He also goes on to state that the location of emergency service facilities should be such that a request for service can be answered by a responding unit within a specified period of time [7].

A technique that has often been used successfully to locate emergency service facilities is to formulate the location problem as a set covering problem. However, the major dilemma with this solution technique is that most often the assumption is made that demand for service is static. Static can mean two things in a network problem. First, it can mean that the servicing resources are always available to respond to a call for service and second, that the demand for service is constant and will not change. Considering today's ever changing economy, a static situation is not at all a reality. The static demand assumption totally disregards the possibility of nodal saturation. Chrissis takes the view that a static situation is not a valid assumption from the standpoint that developing areas are constantly changing and suggests making use of a dynamic set covering model to account for this change [7].

One type of emergency services network that has been extensively studied is the locating of fire stations. The reason for this is purely economic. Fire protection for urban areas is an expensive service. Many municipalities typically spend more than 10% of the city's general revenue fund on fire protection. The major costs associated with fire fighting are labor costs, not facilities or equipment. An extensive operations research study of the Denver Fire Department was conducted in 1972 by the Denver Urban Observatory [9]. The study concluded that there were very high payoffs associated with moving a fire station, when the change in location reduced the annual labor costs by reducing the number of fire companies required to maintain a specified level of fire suppression protection [6].

Mondarachi, Hendrick and Plane write that the Denver research project was accomplished using three different solution techniques [10]. The first two techniques made the assumption that the demand for service was static. This meant that every fire suppression vehicle was always available to respond to an incident. The first formulation was to use a set covering model. The second static model made use of mathematical programming whereby the user could specify various combinations of truck and pumper vehicles. The third approach to the problem was for the researchers to make use of a dynamic (where every vehicle can be already engaged in fighting a fire) analysis computer simulation model developed by the New York City Rand Institute [8]. This solution technique takes into account the possibility

of nodal saturation where the customers in the node having their fire fighting resources engaged must now be provided coverage by some neighboring node.

By combining the results of the three solution techniques, the city of Denver was able to close five fire stations and still maintain an effective level of fire protection. The simulation proved that the static assumption was not valid in that on average five percent of the time a particular fire company could not respond to a call because it was busy [9].

Reilly and Mirchandani describe a mathematical programming model that they formulated as a set covering problem applied to fire station locationing decisions in the city of Albany, New York in 1984 [11]. They contend that their assumption that the problem should be formulated as a static problem is valid because static models are sufficiently representative for locationing decisions in all but the largest cities. This contention was based on a study of fire companies in the city of Alexandria, Virginia where engine companies were only unavailable 7.6% of the time and ladder companies 1.6% of the time [12]. However, Reilly, et al. conclude that the model that they have developed should only be used in well constrained problems and that the solution should only be a guide to decision making.

Over the last three decades, many papers have been written on the problem of estimating demand and need for ambulance services in a particular geographical area. Again, the reason for this research is primarily monetary in that

the design and analysis of health care delivery systems is one of the largest industries in the United States [17]. Here again, the "network" of ambulance services can be thought of as a system of nodes (geographical areas) serviced by a limited number of resources. If the agency responsible for providing the service has not accurately estimated the demand that will be placed upon the resources, ambulance allocation will be inadequate resulting in the possible consequence of loss of human life.

Kamenetzky, Shuman and Wolfe state that the majority of models in existence are not based on accurate data. They contend that estimates of demand have usually been based on rule of thumb estimates or incomplete historical data. This then leads those authors to the contention that the majority of "optimal" solutions arrived at in the current planning models are highly questionable [13].

The preponderance of the studies available in the literature regarding ambulance demand have utilized some form of regression analysis as the solution technique. Aldrich et al. developed a series of regression equations with seven dependent variables [14]. Siler developed a predictive model using regression analysis using five independent variables for publicly dispatched ambulance service in Los Angeles [15]. Kvalseth and Deems developed a model with eight dependent variables and eighteen exogenous variables to estimate the ambulance demand in Atlanta [16]. Kvalseth alone further researched the Atlanta ambulance problem and found that his original model developed with

Deems had severe problems with multicollinearity. He then modified his technique from the method of least squares regression to that of ridge regression which resulted in a significant improvement in reducing the multicollinearity problem with the model [17]. Kamenetzky et al. also utilized regression analysis to develop a similar model and conclude that their work is superior to other efforts due to their extensive use of accurate historical data [13].

The health care industry has recognized the critical need for studying the problem of evaluating emergency service capabilities within geographical nodes. Information gained from these studies possesses considerable utility for the design and evaluation of treatment facilities as well as the determination of emergency service vehicles requirements with regard to the number and types of vehicles, their location and dispatching policies.

Computer Communication Networks

Another network system that is almost entirely thought of in terms of as being nodal is that of Computer Communication Networks. As the technology has improved, the numbers of computers depended on by our society to function on a day to day basis has grown tremendously and along with this so has the need for communication between computers. Tanenbaum has stated that the four main advantages of networking computers are:

1. the convenient use of data that are located remotely,

2. the increase in reliability that results from not being dependent on any single piece of computing hardware,

3. the ease of communication between users, and

4. the savings that accrue from being able to use several smaller processors instead of one very expensive large processor [52].

Badr, Gelernter and Podar have defined a network computer to be a collection of computers designed to function as one machine. In a network computer, as opposed to a multiprocessor, constituent subcomputers are memory disjoint and communicate by some form of message exchange only [54].

Garcia has perhaps provided one of the best definitions and background material regarding computer networks. He has defined a computer communication network as a network consisting of nodes connected by data communication links. Each node is made up of computing machinery which acts upon messages that flow through the network. The node structures of the network are made up of input and output terminals, host computers and switching computers, whereas the data communications links are two way communications paths between nodes that the messages flow through [53]. The control of how messages are routed from the originating node to the destination node through the network is accomplished by the switching computers. These controls are called routing algorithms.

There are basically three methods of routing algorithms in use by computer networks today. These methods are: (1) circuit switching; (2) message switching; and (3) packet

switching [33]. In his dissertation, Garcia provides very simple explanations of each of the three methods.

Circuit switching in computer communication networks is identical to the method most often used in common telephone systems. When a user desires to send a message, an entire path through the network from originating node to destination node is constructed. When the switching computer receives confirmation from the destination station that the path is complete and free, it transmits the message over that path.

Message switching makes use of an algorithm called store and forward. A switching computer transmits an entire message to another node in the network over a free communication link. When that node has received the message in its entirety, it then transmits the message over a communication link to the next node in the network. If the communication link to the next node is busy, the node puts the message into queue (thus the store) until the link is free.

Packet switching is very similar to message switching with the exception that in a packet switched network, every message is broken down into small groups called packets which are then routed through the network. The packets are transmitted in the same store and forward manner as the message switched networks, however the packets will most probably not follow the same path through the network. It therefore becomes an additional requirement for the switching computer at the destination node to reassemble the messages in their correct order [53]. The majority of

computer communication networks in use today utilize the method of packet switching to communicate between nodes.

Seitz sums up the primary advantage of computer networks by stating that network computers are more economical and simpler than shared storage machines. The greater the number of processors, the greater is the advantage to the network user [18]. However, there is a severe disadvantage to computer communication networks. This disadvantage is the fundamental communications problem. Unless the computers within the network are completely connected (which is rarely possible), messages between nodes will have to travel over several links and be processed by several intermediate nodes prior to reaching their destination. As computer networks become larger and more complex, this problem has become a major concern for both users and managers of these networks. In today's highly competitive marketplace, the success or failure of these networks is almost completely dependent on the performance of the network. As a result, computer networks are constantly being studied, modified, and extended with an eye towards performance improvement.

Drukey and Russell have stated that one of the largest problems facing computer communication networks is that of network failure due to the saturation of switching nodes. They have identified this failure to arise due to the fact that the majority of networked computers in use today have a limited number of core buffers. These buffers are dedicated for the temporary storage of packets or messages which are in transit between switching computers. Under some

circumstances, these buffers will be full of packets awaiting transmission into the network. When the buffers are full, the nodes will reject incoming packets and the cooperation between adjacent switching computers breaks down. If the condition described continues, the network fails catastrophically [20].

Russell alone has further researched the problem of nodal saturation and based on this analysis he has determined that packet switching networks can exhibit a bimodal behavior. At normal traffic levels, throughput, which is defined as the capacity of a communications link, or set of links, without regard to delay, increases with demand. However, at saturated levels, increasing the load on a system leads to decreases in throughput. He concludes that this bimodal behavior could cause a network to crash suddenly [21]. This work further describes how he has developed a model which can be easily used to dynamically illustrate the achievement and effects of saturation in a computer communication network.

Here again, the impact of saturation of the nodes of a network caused by a limited number of resources being busy has been clearly illustrated. Computer network designers, managers and providers must continuously study, improve, and monitor the performance of their particular network to preclude the often disastrous impact of nodal saturation.

Communications Networks

Communications networks, both civilian and military are normally discussed as being a series of nodes connected by

communications links. The nodes are usually fixed plant or mobile switching facilities such as telephone switches. Each of these nodes supports a finite number of users or subscribers in a limited geographical area which are connected to the switch by some transmission media. This transmission media can be wire, radio or some more sophisticated means. When a user desires to make a call to another subscriber the switch makes a connecting path between the two subscribers and allows the communication to take place. Switches or nodes are connected to other switches by communication links called trunk lines. Trunk lines can also be wire, microwave radio, multichannel radio, satellite or fiber optic connections.

When a subscriber desires to communicate with a subscriber at a different switch location, the call may be routed through several switches to form the path allowing the communication to take place. Many years ago the connection at and between switches was accomplished manually. Today these connections are entirely automated and are handled by sophisticated network management systems. Prior to the implementation of network management systems and digital switch technology, saturation of both nodes and trunks was a severe problem. Telephone network technology has evolved over the years and numerous improvements have been made. With each improvement the problem of saturation has decreased, finally culminating in the networks in existence today. Although saturation in most "Western" public telephone systems is not an everyday problem, there are

still occasions where saturation is encountered. Mocenigo and Tow of American Telephone & Telegraph state that currently there is extensive research work underway to generate network control strategies for peak traffic days, such as Mother's Day, and other unusual phenomena for which there is advance warning [22].

American Telephone and Telegraph's Bell Laboratories has probably accomplished more research into the problem of network management than any other organization. According to Ash and Mummert the result of this research has been the implementation of the computer controlled Dynamic Nonhierarchical Routing Network (DNHR), which provides network control for the post divestiture nation wide AT&T communications network. The DNHR provides automatic network management controls, automated routing and improvement in the operational efficiency and network performance of the long distance telephone system that millions of Americans use each day [23].

The function of the DNHR that handles node or switch saturation is the Selective Dynamic Overload Control (SDOC). This is a protective control, which means that the control either restricts the traffic entering a congested part of the network or it reduces the number of alternate routing possibilities. When a switch senses that it is approaching its saturation point it sends a signal to other switches connected to it and these switches then reduce the amount of traffic that they send to the near saturated switch. In addition to relieving the load on the near saturated switch,

this action also serves to prevent the saturation from spreading to neighboring switches [22]. Stephen Eick of Bell Laboratories has used computer simulation to model the DNHR in order to test surveillance strategies for adaptive routing. His work compares the resulting simulated network performance to the baseline network performance without adaptive routing whereby he concludes that different surveillance strategies should be applied under differing load conditions [43].

McDonnell and Georganas have researched the problem of blocking in the Advanced Mobile Phone Service which is a cellular telephone network that has been installed in Chicago, Illinois. Their work has centered on using computer simulation to determine the signal channel blocking probability of the network, the effect of varying system parameters on this probability and the mean delays encountered in obtaining a signalling channel [31]. Blocking is defined as the inability for a subscriber to access a channel (frequency) in his cell due to other subscribers holding the channel.

Eklundth and Karlsson have modeled a load sharing facility which enables subscribers in a cellular telephone system to look for free radio channels in more than one cell. Their work is primarily concerned with blocking probability and channel utilization. The model developed is based on Markov chains which they conclude is highly accurate for the system they studied. Their analytical results are compared with computer simulation results with

high accord [32]. This work is different from most others described in this literature review in that it attempts to gain some benefit from node saturation rather than try to avoid it. In a normal cellular telephone system, the cell transmitting and receiving antennas are placed in such a manner that the cell does not permit a subscriber in one node or cell to gain access to a neighboring cell unless it is via a handoff as the subscriber moves across cell boundaries. Here, however, Eklundh and Karlsson are advocating that the nodes or cells be overlapped just so that if all channels in a subscribers cell are busy (saturated), the subscriber can access a neighboring cell.

Tactical military communications systems are nearly always discussed as being nodal. Ricci and Schutzer define the US Army communications system to include all the necessary switched and dedicated communications equipment to support traffic associated with ground based elements of all services in a combat area. The military system provides an analog/digital, switched, multinodal communications network with end to end security for all system subscribers [24].

Tactical military communications systems are much more susceptible to the problem of nodal saturation than their civilian counterparts because military systems are almost always mobile. Because the systems are mobile and are designed to operate in a hostile (combat) environment, they are generally smaller in size and capacity, and are limited in the number of communications resources available.

Techniques to Measure Network Performance

Many solution techniques have been used to solve the problem of monitoring network performance with differing goals in mind. This thesis is primarily concerned with monitoring network performance in order to determine those points in time when it becomes necessary to take actions in order to avoid nodal saturation. The literature provides a wealth of information the different techniques used to solve problems of this type. Several techniques, to include set covering and regression analysis, have already been discussed in this literature review. The following paragraphs will present other techniques.

Kleinrock states that analytic methods used to model computer communication networks have been primarily concerned with theoretical queues. Then the overall network has been characterized as a set of interconnected queues [33]. Classic queuing theory has been largely confined to the study of single server queues [34]. Because of this very complex structures are not responsive to direct analytic solution. He states that the basic approach to analysis using queuing systems is called the decomposition technique. In this technique, complex sets are reduced to a set of well defined single server problems, each having a well defined solution. Following the single server analysis, the network must be synthesized by collecting the individual solutions, and reuniting them to form a composite solution that reflects the properties of the original network [35].

Craveirinha and Sumner have developed a new topology based on the Cartesian product of complete graphs applied to multi exchange networks. Topology as referred to communication networks is concerned with the placement and interconnection of network nodes. The topology selected for a particular network is heavily influenced by node and link reliabilities, the desired degree of control distribution and by available line capacities [39]. The use of graph theory in modeling communications networks has proven to be highly accurate for relatively simple networks. Highly congested networks require somewhat questionable assumptions regarding the independence of link occupancy [39].

In her dissertation, Bengu states that most real life systems are much too complex to allow those systems to be modeled using mathematical techniques. She concludes that computer simulation is the primary technique for analysis of complex and dynamic systems [25]. Bowdon, Mamrak and Salz state that computer communication networks could be modeled using queuing theory or scheduling theory, but that even for simple networks the resulting models tend to become very complex and stringent simplifying assumptions are needed to find solutions. Their work centered on the development of a simulation model for emulating and testing of the ILLINET (the computer communication network for the University of Illinois) [19].

Chlamtac and Franta developed a generalized simulation for computer networks to aid in the investigation of the performance of computer networks at a variety of levels.

Their simulation is highly modular which allowed its application to several existing computer communication networks which include ALOHA, CSMA, BRAM, SUBRAM, MSAP and TDMA [26].

Jeruchim and Shanmugan write that simulation has become the standard tool for communication system analysis and design and that almost every company affiliated with the business of communications networks has a simulation package of some sort [27]. Shanmugan further writes that the approach of using simulation is extremely flexible and allows the modeling of highly complex communications networks to any level of detail desired [28]. Benelli, Cappelini, and Del Re write that due to the number and complexity of subsystems involved in communications networks, the computer simulation is the only practical approach available to the design or systems engineer for a theoretical analysis [41]. Atkinson states that the majority of communications networks involve a complexity that extends beyond the restrictive assumptions required by analytical methods of study. He has accomplished extensive research into modeling circuit switched communications networks using the SIMSCRIPT simulation language [29].

Balaban and Shanmugan write that except for some idealized and oversimplified cases, it is extremely difficult to evaluate communications network performance in the closed form using analytic techniques. They further state that in many situations where the explicit performance evaluation of complex communications networks defy analysis and meaningful

results can only be determined through actual prototype hardware testing or by digital simulation. Because hardware prototype testing is often cost prohibitive and inflexible, they recommend the use of simulation [30].

Pooch, Neblock and Chattergy have designed a somewhat generalized simulation model to be used as a vehicle to study the communication network routing behavior of a wide range of network topologies and routing disciplines. The purpose of their work is to be able to use the simulation model to design computer communication networks. The major concerns addressed in their research are the flow control of messages in order to prevent node and thus network saturation, topology, security, protocol and routing [36].

Kumar has developed a simulation model to study the phenomenon of contention. Contention is defined as the conflict that arises when more than one message arrives at a receiving node for processing at the same time. His work concentrates on using simulation to identify and interpret the presence of contention, to analyze the influence of model parameters on the performance of the network and compare strategies for the resolution of contention [37].

Huang has developed a generalizable simulation model using the simulation language Q-GERT for a hypothetical voice-data communication system with an infinite buffer system. His purpose in developing this model was to allow researchers the flexibility to extend their studies of communication networks. The major reason for his using simulation as his solution technique was that he found that

the most widely used technique in analyzing communications networks to be queuing theory, which he states is extremely time consuming and often impossible to derive theoretical results for complicated systems [38].

The Strategic Communications Continuing Assessment Program (SCCAP) computer analysis is an extensive simulation model that was constructed when the U.S. Navy desired to quantitatively assess the performance of their portion of the U.S. Strategic Communications System. Specifically, the U.S. Navy operates one leg of the United States' nuclear strategic triad which is the submarine launched ballistic missile system. The SCCAP simulation system, which has been in use since 1981, uses discrete event Monte Carlo techniques to simulate the survival of the communication network nodes during a nuclear attack, the failure and repair of node equipment and the quality and time of acceptance of messages at receiver platforms. Since its implementation the simulation has been used to predict the enhancement of the network as a result of major additions to the network and to study modifications in operational procedures. Czajkowski and Peri write that this simulation has truly aided the US Navy in determining both technical and operational methods to improve the current wartime strategic communications to submarines operating worldwide today [40].

Baker, Hauser and Thoet have written of a distributed simulation and prototype testbed (DSPD) developed at the Naval Research Laboratory in 1987. The DSPD testbed provides a software environment where distributed simulation

and prototype models of military radio communications command and control networks can be built. The simulation aspect allows the user to implement specific networks, scenarios, monitor views, and prototyping needs at a fraction of the costs associated with building actual networks [42].

From the vast amount of literature available, it is clear that simulation is the technique of choice when analyzing nodal type networks. Nevertheless simulation also possesses disadvantages. King writes that the level of detail for the model must be carefully chosen, the important characteristics must be included, however, the model must not be so complex that it takes too long to run. Additionally, it is often extremely difficult to interpret the behavior of a system when using a complex model [44]. Law and Kelton write that one disadvantage of simulation is that because of the large volume of numbers generated, often times analysts may place greater confidence in the simulation that is justified. This means that if a simulation is not a true representation of the system under study, the results are meaningless [45,pg 9]. Murry writes that the complexity of message communications networks and the simulation models used to study them often make understanding of the resulting data very difficult and even impractical to use [46].

Although there may be some minor problems associated with using simulation as a technique for measuring network performance, based on the research conducted thus far, it appears to be the best "tool" available. This thesis will

make use of computer simulation to develop a generalized model to analyze a portion of an as yet unfielded U.S. Army mobile communications network that is believed to be highly susceptable to node saturation.

CHAPTER III

PROBLEM DEFINITION

Research Objective

The objective of this research effort is to develop a usable model with a twofold purpose. The purpose of the model will be to: (1) determine the point at which nodal saturation begins to effect a nodal type network and; (2) assess the performance of the network under various loading conditions using standard network performance measures. Using techniques such as the one proposed here for analyzing a network and measuring system performance will allow network managers to better manage their networks and to utilize those networks to their fullest capacity.

To illustrate the utility of this research, a portion of the U.S. Army's Mobile Subscriber Equipment (MSE) tactical communications network will be modeled. The purpose of the simulation will be to determine saturation points of the radio resources that are present at each node of the portion of the network evaluated. Network performance will be evaluated and reported at different loading levels of the network.

The specific portion of the MSE network to be modeled is that of the Mobile Subscriber Radio Terminal (MSRT)-Radio Access Unit (RAU) communications. This particular area of this nodal network was chosen to be simulated based on a problem that the TRADOC System Manager-Mobile Subscriber Equipment (TSM-MSE) operations cell at the U.S. Army Signal

Center (USASC), Ft. Gordon, Georgia desires to be solved [47].

The following section of the thesis provides an overview of the MSE System and then a more specific description of the portion of the system that is modeled.

MSE OVERVIEW

Tactical area communications are needed which will enable US Army commanders and their staffs to exercise command and control from both massed and dispersed Command Posts (CPs) that require frequent relocation. This need includes the transmission of voice and data, to include hard copy traffic, without regard to unit movement and terrain constraints. The US Army's new Mobile Subscriber Equipment (MSE) system was developed to meet this need into the year 2000. This need for a mobile secure automated communications system for combat, combat support and combat service support elements of tactical forces has been accelerated by the fielding of newer technology weapons and support systems [49].

The MSE communications network provides common user communications for a five division corps area of 37,000 square kilometers. The baseline system is self organizing and provides secure voice and data communications on an automatic, discrete address, fixed directory basis using a form of flood search. A flood search algorithm is where once a call is placed by a valid subscriber into the network, the origination calling party's switch sends a search message to all other switches to which it is connected. Each switch

receiving that search message examines its affiliated subscribers for the called number and marks the path from the originating switch. If the called party is not affiliated with the switch receiving the search message, then the search message is forwarded to all other switches that are connected to that switch. It is for this reason that the routine is called flood search in that the entire network is "flooded" until the called party's switch is located. Once the called party's switch is found, it sends a return message to the originating switch over the marked routing path. The originating switch then sends an end of routing message to all connected switches so that all those switches not involved in the marked path can then clear their routing registers of that particular call attempt.

The functional areas of the system that provide a self organizing network include automated affiliation, deducible subscriber numbering and flood search routing techniques. The basic architecture of the network integrates the five following functional areas:

1) Subscriber Terminal,
2) Mobile Subscriber Access,
3) Wire Subscriber Access,
4) Area Coverage, and
5) System Control.

These five functional areas are combined into a three level architecture: the grid system, the extension system, and users [50].

The grid system provides the backbone of interconnectivity through the geographical area that is serviced by the MSE network and the management and control of the network.

The grid system is made up of the area coverage and system control functional areas. The area coverage provides the radio interconnectivity that allows messages to be transmitted from subscriber to subscriber. It is comprised of several Node Centers. Each node center consists of: a Node Center Switch (NCS); up to four Line Of Sight (LOS) radio terminals; two Radio Access Units (RAU); a Management Shelter (MS); and a support vehicle [51]. Figure 1 provides a representation of a deployed operational node center.

The system control for the MSE network provides real time network monitoring, performance evaluation and management of any required reconfiguration of the network.
It is made up of a two or three van configuration called the System Control Center (SCC).

Usually, the SCC is collocated with a node center or a Large Extension Node (LEN). The SCC is provided information on circuits, equipment and personnel from all elements under its control. This information is shared with all other SCCs in the network so that if a particular SCC becomes inoperable another can take over its function. The SCC is comprised of three elements: the technical, command and planning shelters [51]. Figure 2 provides a representation of a deployed SCC.

The second level of the three level architecture is the extension system. The extension system is made up of the wire subscriber access functional area. This system provides the communications switching and transmission equipment for Command Posts (CP) that are serviced by the MSE network.

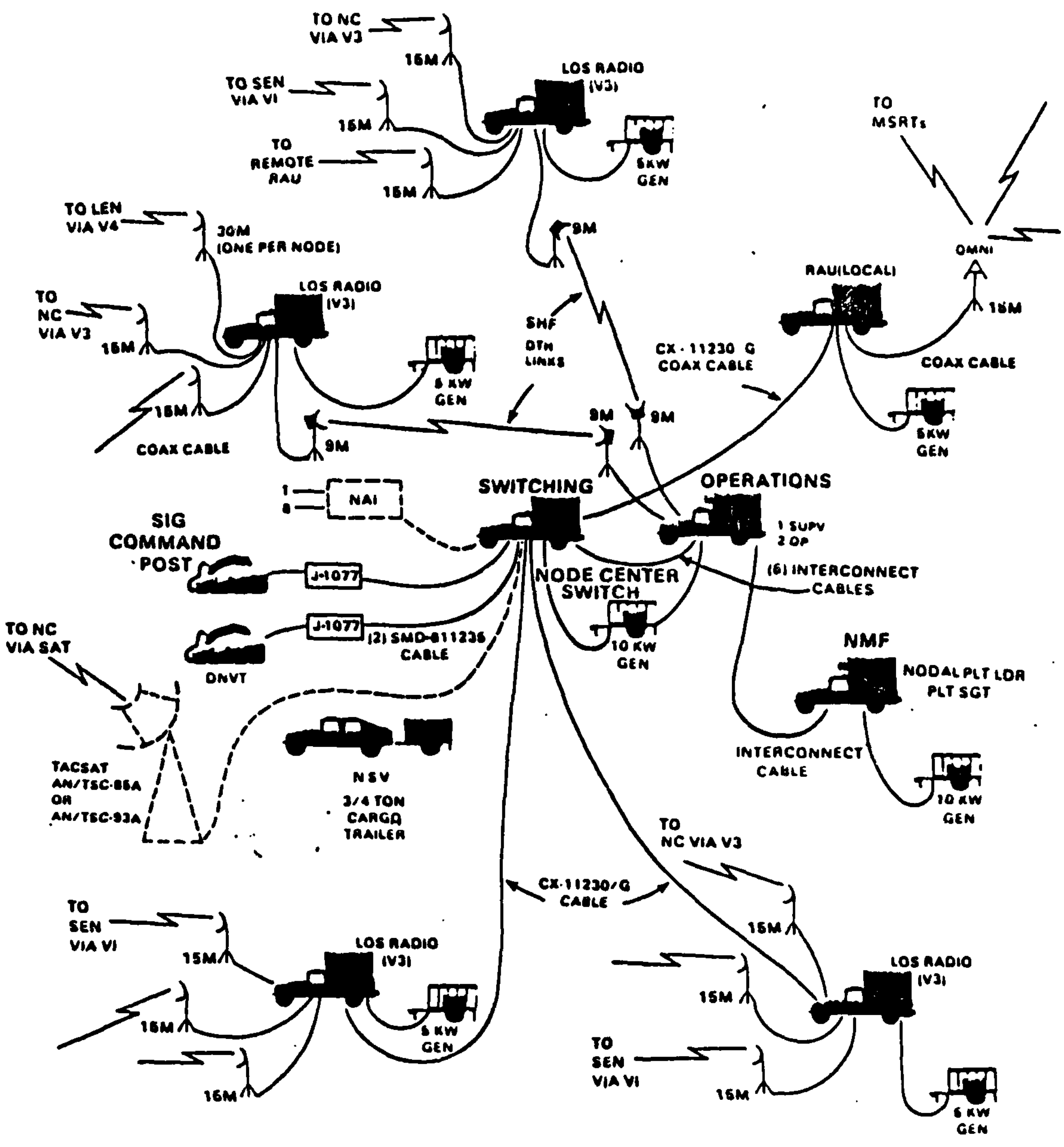

Figure 1. Deployed Operational Node Center

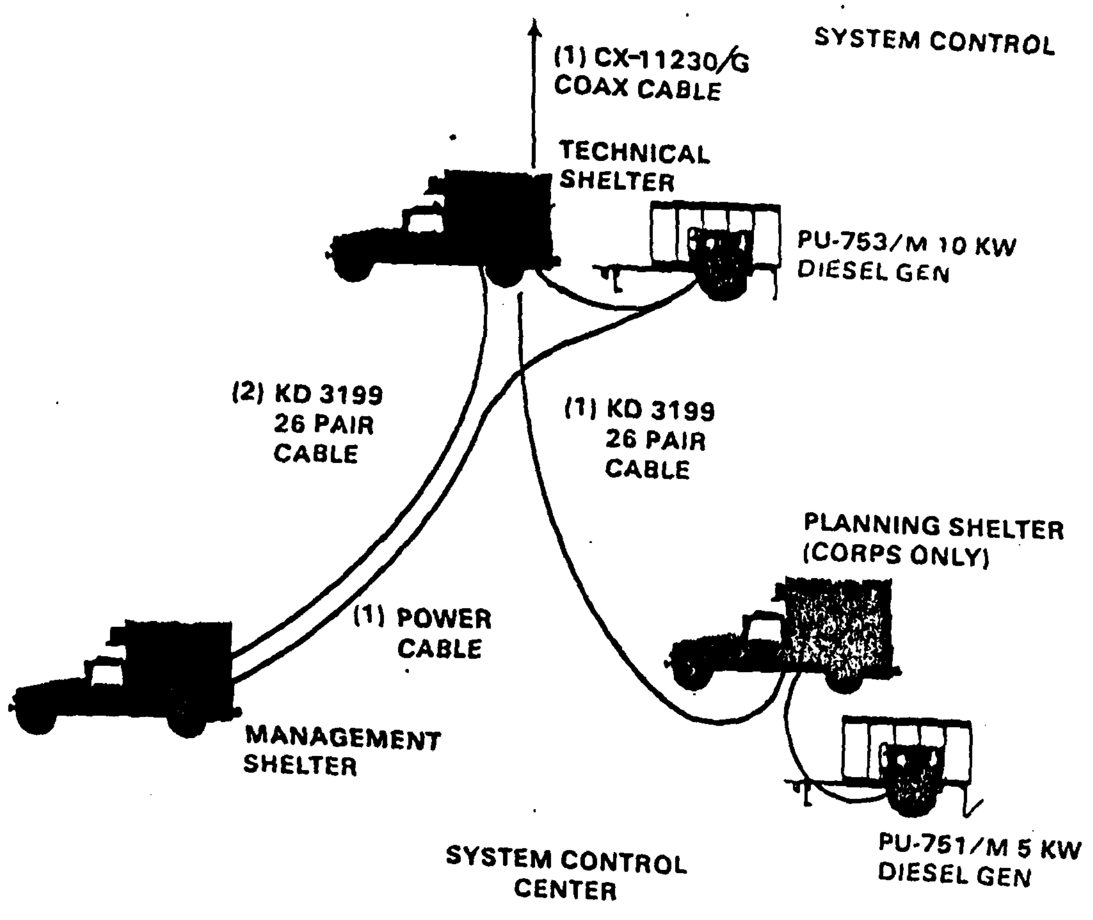

Figure 2. Deployed System Control Center

There are two major assemblages present in the extension system. These are the Large Extension Node (LEN) and the Small Extension Node (SEN). A LEN is comprised of the LEN switch, one LOS radio terminal, a management shelter and a cable vehicle. It is capable of providing a large Command Post with up to 176 subscriber terminations [51]. Figure 3 depicts a deployed LEN while Figure 4 depicts a SEN.

The last level of the three level architecture is the system users. Subscribers of the MSE network are provided access to the network by two functional areas. These are the subscriber terminals and mobile subscriber access. Subscribers in static Command Posts can access the network through the TA-954()/TT Digital Nonsecure Voice Terminal (DNVT), the AN/UXC-7 Digital Tactical Facsimile (FAX) Terminal or send data via the AN/UGC-137A(V)2 Single Subscriber Terminal (SST) compatible data terminal equipment (DTE).

Network subscribers requiring access to the network while away from a CP can access the system by use of the Mobile Subscriber Radio Terminal (MSRT). The MSRT uses a Very High Frequency (VHF) radio (ER-222/M2) and a KY-68 Digital Secure Voice Terminal (DSVT) to establish contact with a RAU and via the RAU enter the network. In its standard configuration the MSRT is known as the AN/VRC-97. The MSRT can be used for data or facsimile transmissions as well as voice traffic and is capable of dismounted use [49].

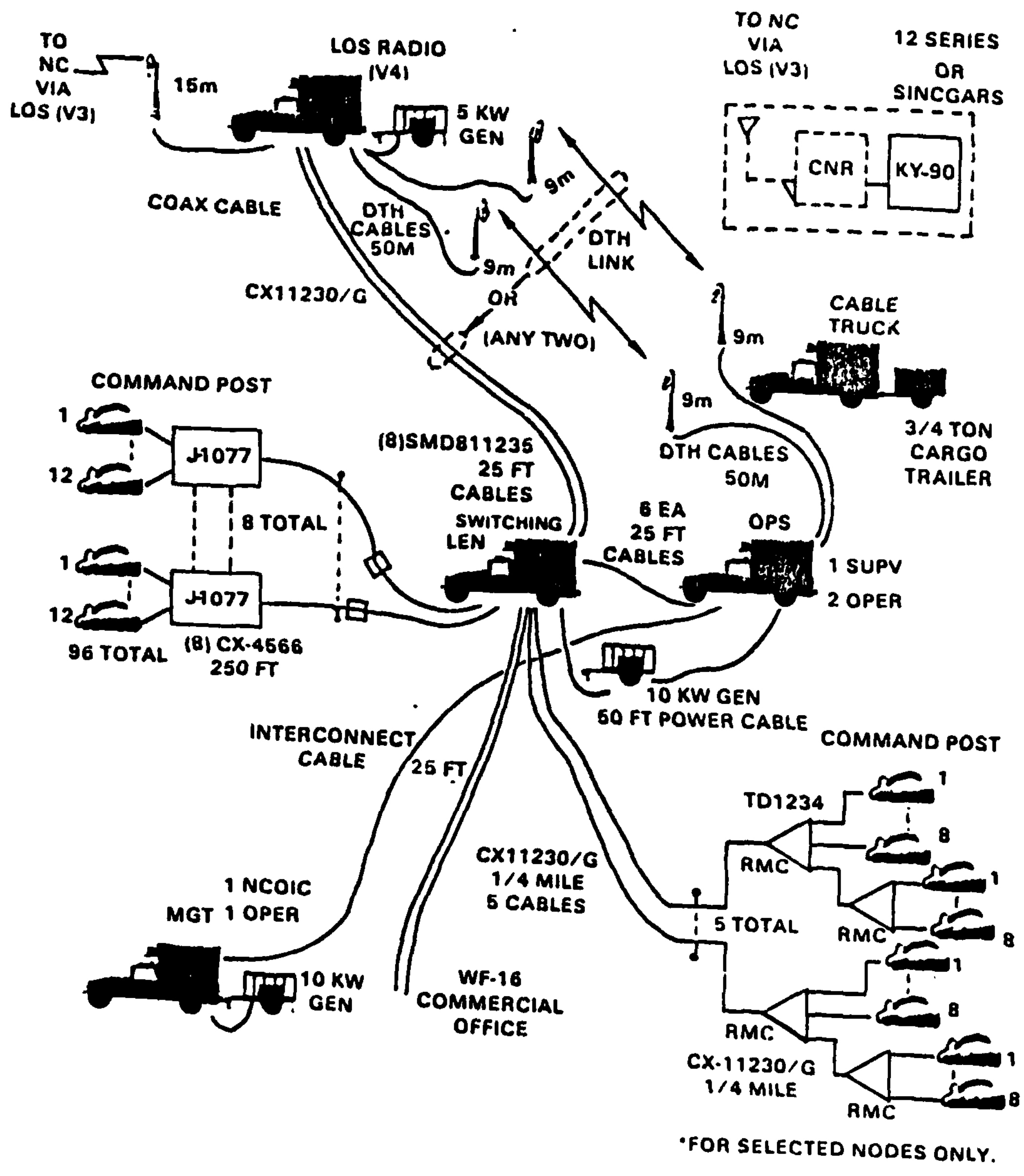

Figure 3. Deployed Large Extension Node

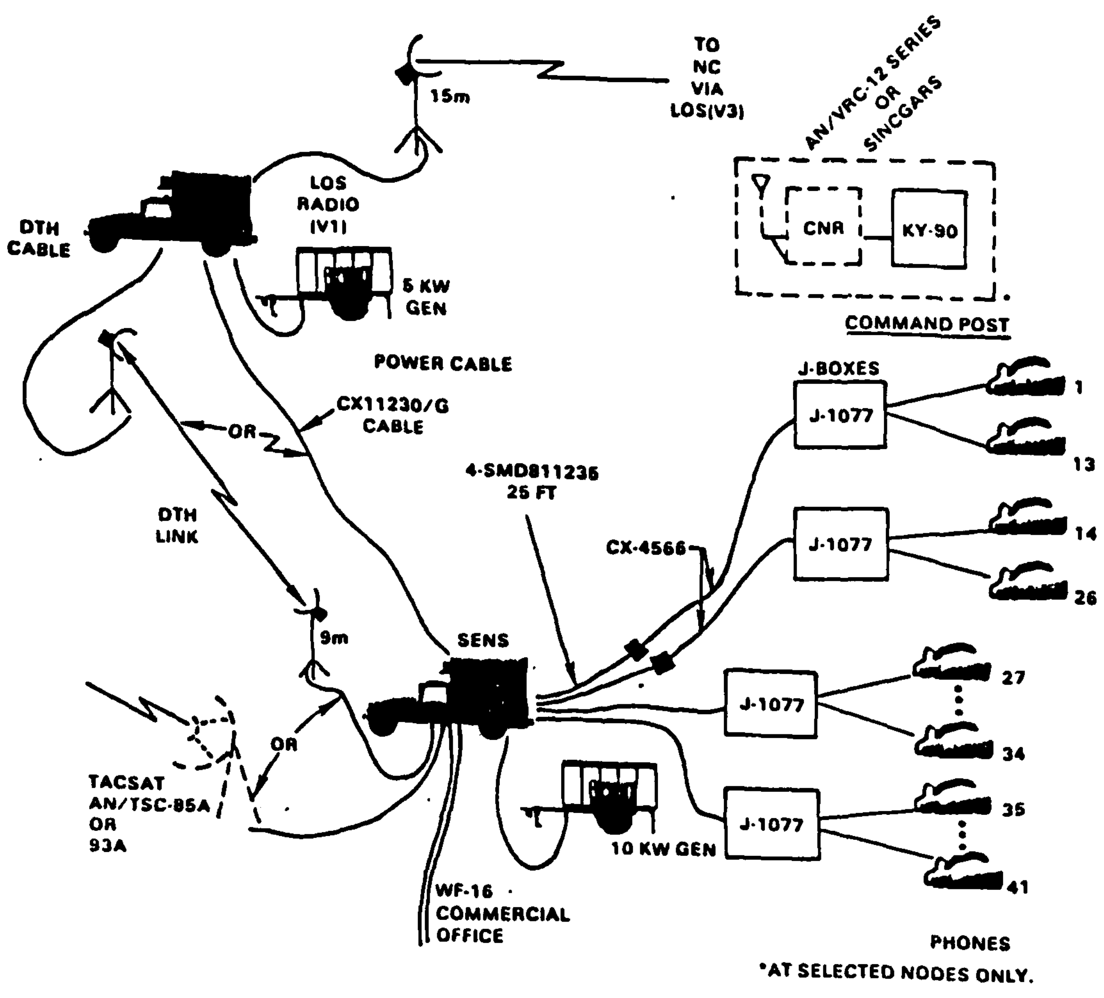

Figure 4. Deployed Small Extension Node

MSRT Communications Description

The portion of the MSE network to be modeled strictly pertains to the Mobile Subscriber Radio Terminal-Radio Access Unit (MSRT-RAU) communications. Each RAU is capable of processing up to a maximum of eight mobile subscriber calls simultaneously. Communication from a mobile subscriber via a MSRT to a RAU makes use of the ER-222/M2 radio. The radio operates in the full duplex mode to provide connectivity from a MSRT into a receiving radio with a high and low frequency band containing the transmit and receive channels. The high band is used for transmitting and the low band for receiving in the RAU. The role of the frequency bands are reversed in the MSRT.

A RAU, which contains eight ER-222/M2 radios, is known as the AN/TRC-191. The RAU serves as the control unit between the MSE network and MSRT subscribers or MSRT to MSRT calls. It acts as an automatic interface in that it does no switching functions. Its primary purpose is to ensure the proper use of the available radio channels as there must be a minimum of 50 kHz between channels.

Each RAU is capable of supporting up to 50 subscribers, however normal operations call for a RAU to support between 25 to 35 MSRT assigned subscribers. As there is a great deal of movement in a division area, the number of subscribers supported by a RAU tends to balance to somewhere in the area of 30 to 35 provided the division has six or seven RAUs operating.

Problem Description

In a typical US Army Division there are 225 assigned MSRT subscribers. Although there are nine RAUs assigned to a division, due to the fluidity of the modern battlefield and normal maintenance requirements, the Division will normally not have more than seven RAUs in operation at any one time. The remaining RAUs will either be moving or in normal maintenance. The typical "footprint" or geographical area that a US Army division operates in is an area of a 50 kilometer front by 100 kilometers deep. The normal area that a RAU provides subscriber coverage for is a circular area with a radius of 15 kilometers. Figure 5 depicts a typical employment of seven RAUs and their zone of coverage imposed on a US Army division "footprint".

In order for the MSE network to know how to reach a particular mobile subscriber, the network must at all times know where each subscriber is located on the battlefield. This is accomplished by the assemblages in the network maintaining automated Subscriber Affiliation Tables (SAT). The SATs are continuously updated to allow a minimum loss of contact. In order for the RAU systems to maintain contact with MSRT subscribers, each RAU has one of its eight radios continuously broadcast a "marker" or "beacon" signal. Each subscriber's MSRT continuously searches the airwaves to find the strongest marker signal. When a MSRT finds a marker signal it sends information to the RAU broadcasting the marker regarding its location and status. With this transmission the MSRT or subscriber is entered in the RAUs SAT and

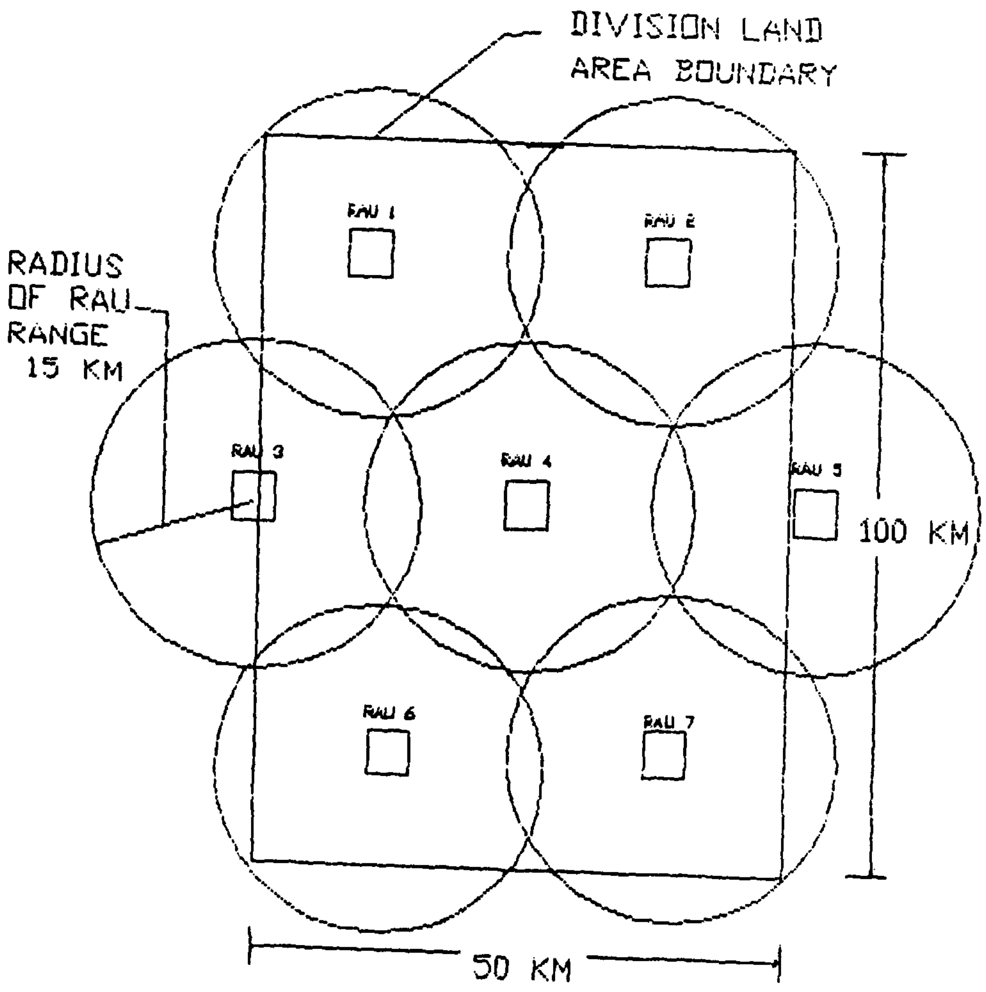

Figure 5. Employment of RAUs on a Division Footprint

the subscriber is then considered affiliated with that RAU. Any calls made or received by that subscriber will be handled by the RAU that it is affiliated with.

As stated previously, each RAU is capable of terminating a maximum of eight simultaneous calls. When an eighth call arrives at an RAU, the radio broadcasting the marker signal stops sending that signal and handles the eighth call. The RAU is then considered to be in a saturated state. The MSRTs that were affiliated with that RAU immediately sense the loss of the marker signal and begin searching for a new signal. When a new marker signal is found the MSRTs then affiliate with the new RAU broadcasting the marker. The new RAU, which probably has at least 30 subscribers affiliated with it, then picks up at minimum 8 to 10 more subscribers. This additional load then causes a greater chance that the RAU will attain a saturated state at a much faster rate. If the neighboring nodes do in fact saturate at a faster rate, then the saturation of one node can cause a condition known as cascading saturation or the "domino" effect. Cascading saturation in a nodal network can cause severe problems, often to the point of total network congestion or failure. Because the MSE System has not yet been totally fielded, the TSM-MSE cell at the US Army Signal Center is highly interested in determining via a computer simulation what effect RAU saturation will have on the MSRT-RAU portion of the MSE network [47].

CHAPTER IV

APPROACH TO THE PROBLEM

Simulation as the Solution Technique

The model developed in this research effort makes use of discrete event computer simulation as the solution technique. This technique was chosen for three main reasons. First, simulation is limited only by the capacity of the computer on which the simulation is performed and the ingenuity of the programmer. Secondly, simulation allows for excellent model structure for experimental manipulation. And lastly, while analytical solution techniques typically require several simplifying assumptions to make them mathematically compliant, simulation has no such requirement.

Modeling Language

The SIMAN simulation language, version 3.51, and FORTRAN, version 4.1 were selected to model the network under study. The SIMAN language, which will accomplish the majority of the simulation, is a combined discrete-continuous simulation language which was developed by C. Dennis Pegden of Systems Modeling Corporation for modeling general systems. SIMAN was attractive for modeling nodal networks for several reasons. A major reason these languages were chosen is SIMAN's capability to make use of user coded FORTRAN subroutines to perform operations that the SIMAN language was not designed to accomplish. Another reason was because of SIMAN's modeling framework, which is based on the work of

Zeigler and Oren. Their work stressed the distinction between the system model and the experimental frame. A system model specifies all the characteristics of the system under study while the experimental frame specifies the experimental constraints under which the model will be run. The system model usually remains unchanged while different experiments can be conducted by simply changing the experimental frame [48, p 1].

Another reason that these two languages were chosen is that this author has taken several classes in these languages, is comfortable in programming simulations with them, and has ample access to them in the Industrial Engineering Department of Clemson University.

Lastly, SIMAN is a FORTRAN based language that was primarily developed for use on mini and 16 bit microcomputers. This is an extreme benefit to this research in that one of the underlying goals of this work was to develop a model for use at lower organizational levels of the U.S. Army and other large network users where the primary computing capability is 16 bit microcomputers. This then will allow the simulation of nodal networks to take place at the operations level as opposed to specialized operations research cells, where most modeling is presently accomplished.

Model Parameters and Assumptions

In order to accurately model this network, several U.S. Army doctrinal parameters must be understood and some assumptions have to be made. These are detailed in the following paragraphs.

The ideal case for any communications network would be to provide half as many switches as there are subscribers being serviced, thus allowing an almost absolute probability of call completion. However, as has been pointed out earlier, this is not economically feasible. Therefore, in order to reduce the number of servicing nodes or switches to an economically feasible level, it is necessary for subscribers to realize that some of their calls cannot be immediately handled when other subscribers are using the limited resources of the network. The term Grade of Service (GOS) in telephone traffic engineering is given as the proportion of these unsuccessful calls relative to the total number of calls made. GOS is defined as a measure of service given in a telephone exchange from the point of view of insufficiency of the plant equipment [56, p 6].

In this research the RAUs do not act as switches, however they do provide the control for subscriber communications, so a somewhat modified form of the performance measure Grade of Service is appropriate and will be reported in the simulation. Therefore, the term Grade of Service for the purposes of this research will be defined as the ratio of successful calls placed to the total number of calls placed exclusive of retrys. The GOS requirement that was specified to the manufacturer of the MSE network by the US Army was a figure of 90%. Any situation where the simulation output provides a GOS value of equal to or greater than 90% will then be considered satisfactory.

All users of military communications systems are given five levels of user assignable precedence in order to complete their calls. Higher precedence traffic takes priority in seizing lines, trunk groups or other common equipment. In descending order these five precedence levels are: Flash Override (FO), Flash (F), Immediate (O), Priority (P), and Routine (R). It is left up to the user to determine the criticality of the information that he or she is attempting to pass and then place his or her call according to the appropriate precedence. In theory this precedence system then allows for truly critical traffic to be passed if the system is adhered to by all users. Communications doctrine calls for most messages or calls to be made at the Routine and Priority levels with critical traffic to be passed at the higher levels. However, it is a well known fact that precedence abuse takes place in U.S. Army communications networks, especially among higher ranking users. The MSRT equipment is only assigned to higher ranking individuals in a division. Therefore it is expected that MSRT-RAU communications will be subject to precedence abuse. Because of this expected precedence abuse, the following distribution for the precedence of calls to be assigned in the model was chosen: Flash, 30%, Immediate, 20%, Priority, 25%, and Routine, 25% [47].

A protective feature designed into the RAU to provide automatic traffic load control is provided through a presaturation radio protocol feature. This feature was integrated into the system in an effort to combat precedence abuse. The

RAU recognizes two levels of precedence: Routine and Priority. Table I shows the integration of RAU and standard US Army communications precedence levels.

Table I. Integration of RAU and Standard Army Communication Precedence Levels

STANDARD PRECEDENCE LEVELS	RAU PRECEDENCE LEVELS
FLASH OVERRIDE	PRIORITY
FLASH	PRIORITY
IMMEDIATE	PRIORITY
PRIORITY	ROUTINE
ROUTINE	ROUTINE

Each RAU can be set to one of the three following presaturation modes: Automatic Presaturation, Force Presaturation, or Inhibit Saturation. The RAU operator manually selects the desired mode depending on traffic levels.

If the Automatic Presaturation mode is selected, only priority calls can access the RAU when two or less radios are available for traffic. If the Force Presaturation mode is selected, only priority calls can access the network regardless of how many radios are in service. If the Inhibit Presaturation mode is selected, all calls can access the network. Guidance has been provided to this author by the TSM-MSE that the majority of the time each RAU in the network will be operating in the Automatic Presaturation Mode [47]. Therefore, the simulation will model the Automatic Presaturation Mode.

Due to normal divisional movement and maintenance requirements, it is assumed that only seven of the nine assigned RAUs will be operating at any given time. Therefore the simulation will model the operation of seven RAUs deployed on a 50 kilometer wide by 100 kilometer deep land area. An illustration of the deployment modeled is shown in Figure 5, found in the previous chapter.

As was previously stated, the nominal range that a RAU will provide subscriber coverage for is a circular area with a radius of 15 kilometers. It is assumed that due to the reasonably high power output of the RAUs ER-222/M2 radios, a subscriber located in range of one RAU will be able to locate the marker signal of and reaffiliate with an immediate neighboring RAU if its parent RAU goes into saturation. To model the reaffiliation/unreaffiliation of subscribers in a division, Table II depicts the reaffiliation rule that was set for this model. The RAU identifying numbers coincide with those shown in Figure 5. The rule that was decided upon assumes that if a RAU goes into saturation those subscribers that were affiliated with that node who are not involved in a call will reaffiliate with the parent RAUs immediate neighbors in an equal manner. For example, if RAU 2 goes into saturation then the remaining 24 subscribers not involved in a call will reaffiliate with RAUs 1, 4 and 5. Each of these three RAUs will receive eight subscribers. If one of the three possible reaffiliation RAUs are also saturated then the 24 subscribers will be broken down into two groups of 12 and reaffiliate with the two available RAUs. If two of the pos-

sible reaffiliation RAUs are saturated then all 24 subscribers will reaffiliate with the available RAU. And, if all of the possible reaffiliation RAUs are saturated then those 24 subscribers will be considered unaffiliated and thus unable to communicate in the network until such time that a RAU becomes available for them to affiliate with. The model will keep track of the subscribers parent RAU and reaffiliations so that if the RAU that subscribers are currently affiliated with goes into saturation, those subscribers will reaffiliate with only the RAUs that they are capable of reaffiliating with.

Table II. Reaffiliation Rule

Subscribers Parent RAU	Possible Reaffiliation RAUs
1	2, 3, or 4
2	1, 4, or 5
3	1, 4, or 6
4	1, 2, 3, 5, 6, or 7
5	2, 4, or 7
6	3, 4, or 7
7	4, 5, or 6

As previously stated, there are 225 assigned MSRT subscribers in a typical division. In order to make the number of subscribers more easily divisible by the seven RAUs it will be assumed that the division modeled has 224 MSRT assigned subscribers. It will further be assumed that the 224 MSRT subscribers are evenly distributed across the divisional land area resulting in a total of 32 subscribers affiliating with each of the seven RAUs. The effect of MSRT subscriber

movement from RAU to RAU will be ignored. This is based on the assumption that subscriber movement will be constant and tend to balance across the entire division. This means that a subscriber whose parent RAU is RAU 1 will move into RAU 2s range (and now have a new parent, RAU 2) at the same time a subscriber whose parent is RAU 2 is moving into RAU 1s range. Based on this assumption the desired "baseline" of the network will be to maintain 32 subscribers affiliated with each RAU.

Telephone traffic studies have shown that there are specific patterns of calling rates even though subscribers may place calls at various times during a day. These studies have further shown that it is possible to identify a single hour during the day when peak traffic occurs. This single peak hour each day is referred to as the busy hour. The average busy hour is most often made the basis for designing telephone systems [56, p 5]. The output of the simulation model in this research will be considered representative of the MSRT-RAU worst case system response under the expected loads of an average busy hour.

One important point that must be made regarding subscriber behavior deals with a source of load behavior on the system. This is the behavior of subscribers in dialing and upon receiving a busy signal or notice that their call cannot be completed. It has been observed that more than 90% of all subscribers will redial a call within some seconds after an unsuccessful call attempt. These redials are called retries. Since retries no longer constitute random occurrences, they

produce wider than normal load variations [55, p 5-8]. This model will include one retry per unsuccessful call, made after a time delay that is exponentially distributed with a mean of 15 seconds [57].

Input Data

The US Army's standard reference for telephone traffic engineering is Field Manual 11-48-2, Telecommunications Engineering Traffic, dated January 1978. According to this document, and several others regarding telephone traffic characteristics, an individual telephone subscriber rarely is able to predict when he or she will make a call. However, it is an absolute necessity that the both the manufacturer and operating agencies of telephone networks be able to predict the number of subscribers who will be making calls at any given time to provide systems that will meet with customer satisfaction levels. The use of probability theory enables traffic managers to confidently make these predictions.

Because subscribers originate calls in a random fashion the most common statistical distribution used to describe call arrivals is the Poisson distribution [55, p 5-13]. Organizations that accomplish communications network simulations utilize the Poisson distribution almost exclusively when describing call arrival rates [57]. One attractive feature of this distribution is that the variance is not independent of the mean so that it is only necessary to know the mean value. This model will be run using several different means for call arrival rates. The reason for this is because the MSE system has not yet been fully fielded and

there is no true input data available. The purpose of using several means to run the model is to construct a graph of grade of service versus total system saturation level at different call arrival rates. It is hoped that once the system is totally fielded, this graph will include a large enough range of call arrival rates that will enable the network managers the opportunity to exert controls upon the system at critical traffic levels to avoid high saturation levels and thus improve customer satisfaction levels [60].

Real telephone traffic and its theoretical description embrace the definition of the distribution function of the length of the call, called the holding time. Holding time is usually classified into two categories, constant and variable. Constant holding time applies only to the mechanics necessary to set up the call connection. Variable holding times apply to subscriber conversations. Only the variable holding time will be considered in this simulation. Because the actual switching functions are external to the MSRT-RAU communications system it will be assumed that the constant holding time is negligible and will be ignored.

It has been found through numerous examinations of real telephone traffic that call holding times closely follow the statistical distribution known as the exponential distribution [55, p 5-15]. Therefore this system will be modeled using a holding time that is exponentially distributed. Two different means, 3.0 minutes and 5.0 minutes will be used to allow an understanding of how the model behaves at two different levels that are most likely to be encountered. These

means were chosen based upon two partial extracts from the Communications Requirements Database (CRDB). This database was formulated by Teledyne Brown Engineering under contract to USASC. The CRDB consists of the message traffic load information of 463 Table of Organization and Equipment (TOE) units from platoon to corps level oriented towards the units operating in the European theater.

The database is organized into sections of traffic loads as would pass through each major assemblage making up the MSE network. The CRDB is used by the Signal Center for providing message input parameters for studies pertaining the MSE network. The number of calls handled via MSRTs was extracted from the portion of the database pertaining to MSRT and RAU traffic provided in dBase III format. The data consists of all messages that an authorized user belonging to one of the TOE units would transmit in a 24 hour period. The data provides type of message (voice or data), message length, subject and precedence. This material allows the construction of message traffic for every force organization that is used by the US Army.

The data comprising the CRDB was compiled by Teledyne Brown through an extensive survey process. Proposed MSRT users were surveyed as to all possible messages they would transmit during wartime while operating in an European theater of operations. The results were then entered into the database.

Model Development

The model developed in this research is titled the COMM-Q Model. It is a queue oriented model that it is made up of a somewhat generalized shell that has been modified to include specifics of the MSRT-RAU system. COMM-Q consists of a main model and fourteen submodels. The main model serves to create the call arrivals to the system, assign information regarding the call to the call and direct those arrivals to the servicing RAU. Seven submodels model the operation of each of the RAUs in the network and seven submodels model the marker signal at each of those RAUs. All seven of each type of submodel are identical with the exception of label names, so for brevity sake, only one of each type will be described in this section of the thesis. The following section details the operation of the main model, the RAU1 submodel and the marker signal for RAU1. The logic flow diagrams of the main model, the RAU submodel and of the marker signal submodel are shown as Figures 6,7 and 8 respectively.

At the main model, entities (call arrivals) are created according to a poisson distribution with a mean that is specified in the experimental frame in parameter set 10. Global variable X(38) is incremented each time an entity is created. The entity's attribute 8 is then assigned the current value of variable X(38). This allows each call arrival to be assigned a unique identifying number which aids in any debugging that may be necessary. The entity's attribute 1 is assigned a value of 1 through 7, indicating which RAU will

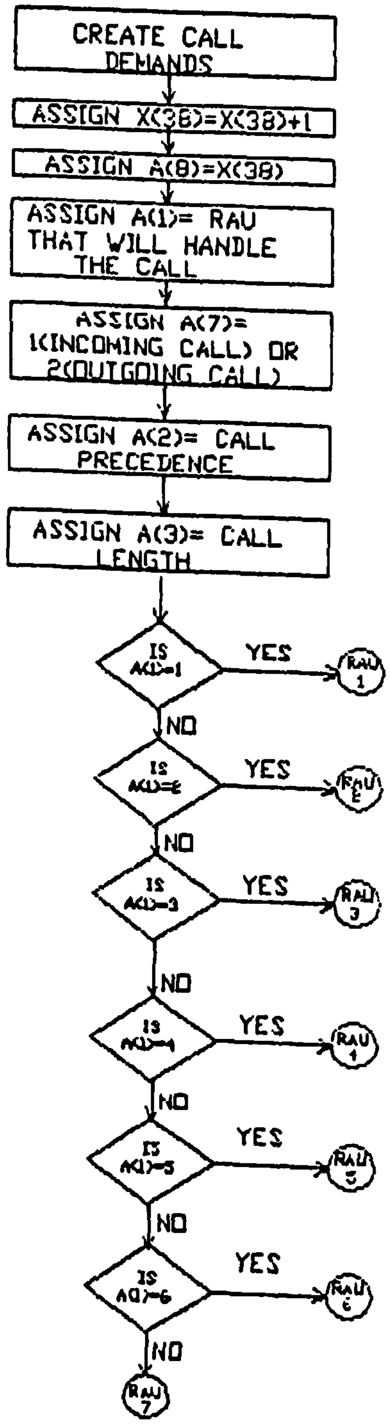

Figure 6. Logic Flow Diagram of the Main Model

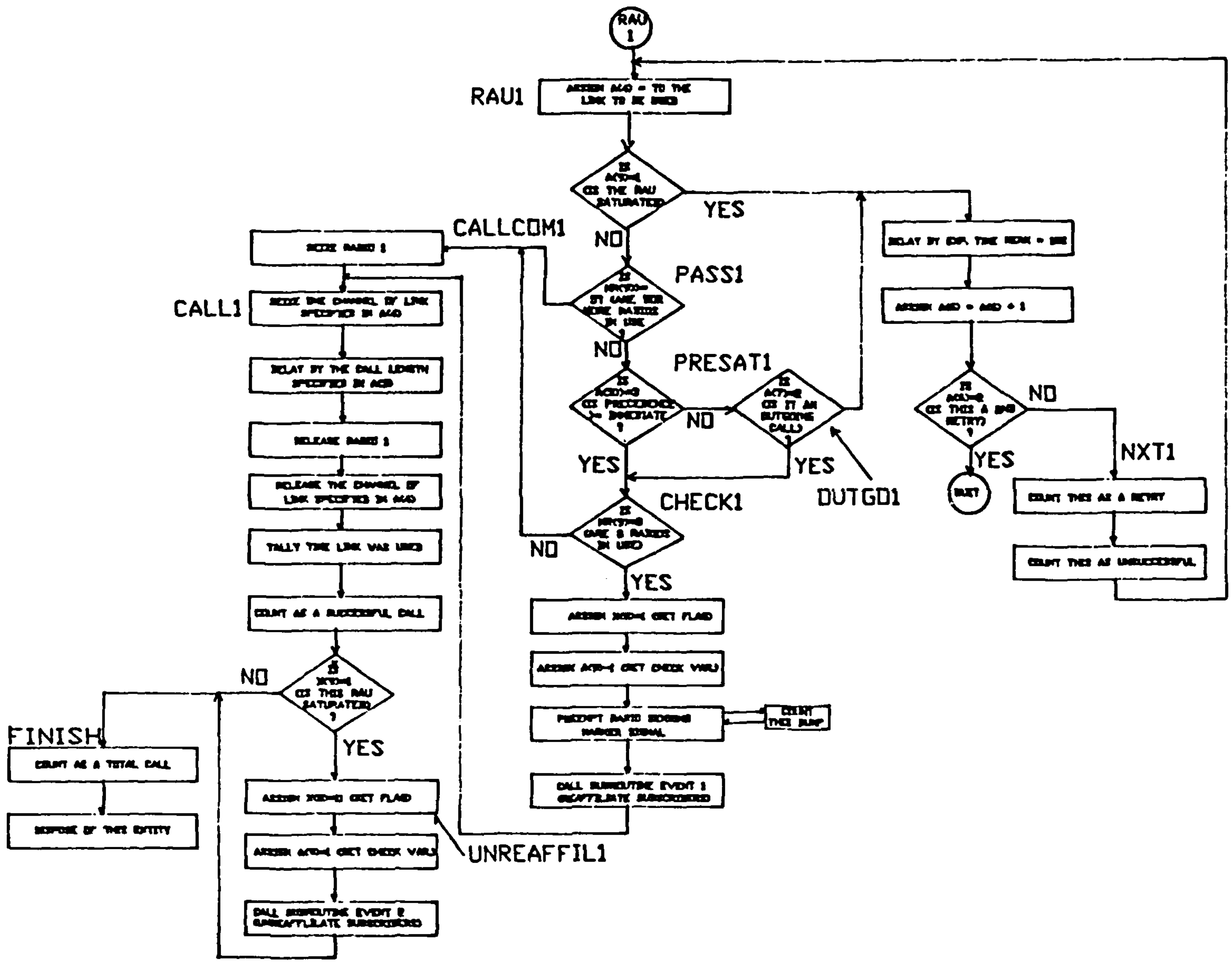

Figure 7. Logic Flow Diagram of the RAU 1 Submodel

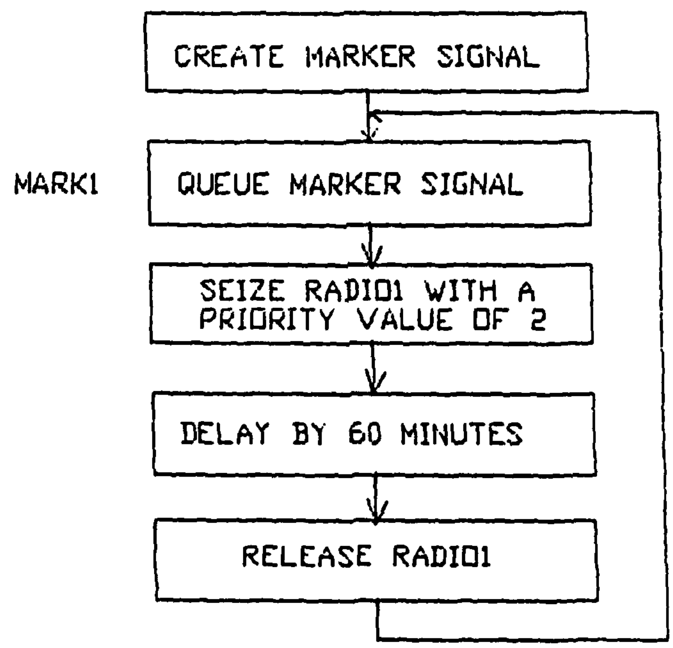

Figure 8. Logic Flow Diagram of the Marker Signal for RAU 1 Submodel

service the call. This value is assigned based on a discrete probability which is dependent on the number of subscribers affiliated with each RAU. The proportion of call arrivals destined for each node is calculated by the FORTRAN subroutine EVENT dividing the current number of subscribers affiliated with each RAU by 224 (total subscribers). If each RAU has 32 affiliated subscribers, each RAU will then receive one seventh of all call arrivals. Parameter set 11 holds the distribution based on these ratios.

The entity's attribute 7 is then assigned a value of 1 or 2 to indicate whether the call is an incoming call to one of the subscribers affiliated with the RAU or an outgoing call from one of the subscribers affiliated with the RAU respectively. The incoming/outgoing assignment is based on a discrete probability of 50% incoming and 50% outgoing. The calls precedence value is then assigned to the entity's attribute 2. This value can be 1 through 4 corresponding to the following precedence levels: (1) Routine, (2) Priority, (3) Immediate, and (4) Flash. Parameter set 1 holds the distribution of the precedence assignments. The remaining assignment accomplished in the main model is that of call length. This value is assigned to the entity's attribute 3 based on an exponential distribution with a mean that is specified in parameter set 2.

The entity then encounters a BRANCH block where based on the value of its attribute 1 (RAU assignment), it will be routed to the appropriate submodel. The following

description will specify those actions that take place at the submodel RAU1.

The first action at the label RAU1 is for the entity's attribute 4 to be assigned a value corresponding to the link that will be used to carry the call. The assignment is based on a discrete probability which differs for each RAU. The number of the link used also serves to represent the call's origin or destination. A link value of 8 represents any location outside the division area. The assumption was made that the subscribers would make or receive the majority of their calls to or from subscribers located in neighboring RAUs. This is predicated on the fact that communications normally take place with a subscribers own unit or his headquarters unit which is typically located close to the subscriber. The remaining communications are equally distributed around the division area with a small percentage of calls being made outside the division area. Table III depicts the links to be used for each RAU and the associated probability for that link being chosen.

The call then encounters a BRANCH statement where a check is made of the value of global variable X(9). This is RAU1's saturation flag. If the value is 1 indicating that the RAU is in a saturated state, the call is considered unsuccessful and routed to the label HOLD11. If the value of X(9) is not 1, the RAU is not saturated and the entity is routed to label PASS1.

At the label HOLD11 another BRANCH block is encountered where the value of the entity's attribute 6 is checked. If

Table III. Link Assignment Probabilities by RAU.

RAU	LINK	PROBABILITY	RAU	LINK	PROBABILITY
1	2	20%	2	1	20%
	3	20%		4	20%
	4	20%		5	20%
	5	12%		2	12%
	6	12%		6	12%
	7	12%		7	12%
	8	4%		8	4%
3	1	20%	4	1	20%
	4	20%		2	20%
	6	20%		3	20%
	2	12%		5	20%
	3	12%		6	8%
	5	12%		7	8%
	8	4%		8	4%
5	2	20%	6	3	20%
	4	20%		4	20%
	7	20%		7	20%
	1	12%		1	12%
	3	12%		2	12%
	5	12%		6	12%
	8	4%		8	4%
7	4	20%			
	5	20%			
	6	20%			
	1	12%			
	2	12%			
	3	12%			
	8	4%			

the value of attribute 6 is greater than 1, then the call is known to be a second retry and the call is routed to the label QUIT where it accomplishes a dummy operation and is disposed of. The dummy operation is necessary because an entity cannot be directly routed to a dispose function in the SIMAN language. If the value is not greater than 1 the call is routed to label NXT1 where it is counted in counter 8 (unsuccessful call at RAU1) and counter 23 (retry at RAU1) and then routed back to label RAU1 to be retried.

At label PASS1 a BRANCH block checks the number of active radio resources at the RAU. If the number of radios in use is greater than or equal to 5, the call is routed to label PRESAT1. If the number of active radios is less than 5, the call is routed to CALLCOM1. For those calls that are sent to the CALLCOM1 label, each call enters a queue and immediately seizes one of the 8 available radio resources atRAU 1 and routes to CALL1 which will be described later. At the PRESAT1 label a BRANCH block checks the precedence value of the call to ensure that only calls of precedence assignment flash and immediate are processed. The calls that are processed are sent to label CHECK1. Those calls of a lower precedence are routed to the label OUTGO1 where the value of attribute 7 is checked to determine if the call is incoming or outgoing. Incoming calls of a lower precedence cannot be processed as the RAU is modeled to be in the Automatic Presaturation Mode. These calls are considered to be unsuccessful and are routed to label HOLD11 which was described earlier. Outgoing calls of lower precedence in

the Automatic Presaturation Mode are allowed to be processed so they are then routed to label CHECK1.

At label CHECK1, a BRANCH block checks to see if all 8 radios in the RAU are in service. If all 8 are in service the call must preempt the radio broadcasting the marker signal in order to be processed. This is accomplished by the entity being routed to label REAFFIL1. If all 8 radios are not in service the call is routed to CALLCOM1. At the REAFFIL1 label, the flag (global variable X(8)) indicating which RAU is saturated is set to 1 (indicating RAU 1), the entity's attribute 9 is set to 1 (used in the FORTRAN subroutine), the call enters a queue and immediately enters a PREEMPT block. At the PREEMPT the call takes the radio resource away from the marker signal. The preempted marker signal's (a separate entity) remaining delay time is stored in its attribute 5 and it is routed to OUT1 where it is counted and routed to label MARK1 which will be explained in the marker submodel. Following the PREEMPT block, the entity calls FORTRAN subroutine EVENT1. This subroutine causes the subscribers that were affiliated with the now saturated RAU to affiliate with the RAUs immediate neighbors. The subroutine will be explained later in this section. Following the reaffiliation of subscribers the subroutine then returns to the SIMAN submodel where the call that bumped the marker signal is then routed to label CALL1.

At the CALL1 label the entity enters a queue and its attribute 5 is assigned the current clock time. It then immediately seizes the link specified in its attribute 4.

The call is then delayed by its holding time indicated in Attribute 2. Following this delay the call releases the radio resource and the link and is then routed to label TAL1. TAL1 is a TALLY block that maintains observation statistics on how long the call held the link that was used.

The next action is that the call is counted in Counter 1 as a successful call. It then encounters a BRANCH block where the RAU1 saturation flag (global variable X(9)) is checked to see if the RAU was in a saturated state. If the RAU was in a saturated state, the conclusion of this call indicates that one of the radio resources is available to begin broadcasting the marker signal. In this case the flag has a value of 1 so the call is routed to label UNREAFIL1. If the RAU was not saturated the call is routed to label FINISH where it is counted in counter 22 (total calls) and disposed.

At the UNREAFIL1 label the flag indicating current RAU saturation (global variable X(8)) is assigned a value of 11. This indicates that RAU1 is no longer in saturation. Next, the entity's attribute 9 is assigned a value of 1 (which tells the FORTRAN subroutine that RAU1 is unsaturating) and FORTRAN subroutine EVENT 2 is called. This subroutine causes those subscribers that reaffiliated to neighboring RAUs to affiliate back with their parent RAU. This models the fact that the stronger marker signal would be sensed by subscribers within range and affiliate with that RAU. This subroutine will also be explained in greater detail later in this section.

The submodel for the marker signal at RAU1 begins at time zero by creating one entity which enters a queue at label MARK1 and immediately seizes one of the 8 radio resources at RAU1. The entity then delays the resource for 60 minutes. It should never achieve the total delay time if the RAU saturates as the priority of seize is 2. An entity with a priority seize of 2 in SIMAN is capable of having a resource preempted by an entity whose priority of seize is 1. All call arrivals are modeled to seize the radio resources with a priority of 1. Therefore the marker signal entity will only hold the radio in the marker mode until it is preempted by a call at the time its parent RAU reaches the saturation point. The FORTRAN subroutines used in this model consist of subroutine EVENT, SUB1, PRIME and FUNCTION UR (user rule). These will be explained in depth below.

Subroutine EVENT consists of two separate actions. These actions are the reaffiliation of subscribers from a RAU that becomes saturated and the unreaffiliation of subscribers from a RAU that unsaturates. The appropriate action is accomplished depending on the EVENT called by the SIMAN program. Event 1 is the reaffiliation action and EVENT 2 is the unreaffiliation action. Both actions make use of two matrixes that are established by the FORTRAN code. Matrix M1 is a table that indicates where subscribers are capable of reaffiliating to and maintains saturation flags for the RAUs. Matrix 2 is a table that keeps track of where subscribers are currently affiliated and the RAU from which they came.

Figure 9 depicts the two matrixes as they would be shown if RAU3 were to go into its first saturation.

When EVENT 1 is called the subroutine sets the variable I equal to the value of the entity's attribute 9. This value can be 1 through 7 depending on which RAU just went into saturation. The matrix location indicating that the RAU is now saturated (M1(8,I)) is set to one, the matrix location indicating the number of times the RAU had gone into saturation is incremented by one, and the SIMAN variable that indicates the RAU is saturated is also set to one. For example, if RAU3 were to go into its first saturation, M1(8,3) would be set to 1, M1(9,3) would be incremented by one and SIMAN variable X(11) would be set equal to 1.
The next action is for the SIMAN variable X(37) to be incremented by 0.143857142. This represents 1/7th of the network being in a saturated state. The SIMAN program maintains time persistent statistics on variable X(37) so that a total network saturation level can be presented at the conclusion of the simulation.

The subroutine then performs a DO loop where each matrix location in the saturating RAUs column of matrix M1 is checked. The check is to determine if there are possible subscribers from this RAU at the RAU indicated in the matrix location. When a number of subscribers is located (the matrix location will show 1 or 2) the variable NA will be set equal to the number of subscribers in the same matrix location in matrix M2. In the case where the matrix location indicates the RAU going into saturation NA will equal the

MATRIX M1

SUBSCRIBERS PARENT RAU (COLUMN)

	RAU1	RAU2	RAU3	RAU4	RAU5	RAU6	RAU7
RAU1	2	1	1	1	0	0	0
RAU2	1	2	0	1	1	0	0
RAU3	1	0	2	1	0	1	0
RAU4	1	1	1	2	1	1	1
RAU5	0	1	0	1	2	0	1
RAU6	0	0	1	1	0	2	1
RAU7	0	0	0	1	1	1	2
SATURATION FLAG			1				
NUMBER OF SATURATIONS			1				
UNAFFILIATED SUBSCRIBERS FLAG							

SUBSCRIBERS CAN REAFFILIATE WITH RAU'S THAT HAVE A 1 IN A MATRIX LOCATION. A 2 INDICATES THE SUBSCRIBERS ARE AT THE PARENT RAU.

MATRIX M2

SUBSCRIBERS AFFILIATED WITH RAU (COLUMN)

	RAU1	RAU2	RAU3	RAU4	RAU5	RAU6	RAU7
RAU1	32						
RAU2		32					
RAU3	8		8	8		8	
RAU4				32			
RAU5					32		
RAU6						32	
RAU7							32
TOTAL AFFILIATED SUBSCRIBERS	40	32	8	40	32	40	32
UNAFFILIATED SUBSCRIBERS							

ROW INDICATES WHERE SUBSCRIBERS CAME FROM

Figure 9. Matrixes Used By FORTRAN Subroutines

number of subscribers at the RAU minus the eight subscribers actively engaged in calls. The matrix location in M2 is then assigned a value of 0 or 8 depending on the situation described above. The subroutine then calls subroutine SUB1 carrying the value of NA and KA (the RAU where subscribers previously came from).

At subroutine SUB1, a 1 by 6 matrix is immediately established and all locations are assigned a zero value. A DO loop then checks matrix M1 for the RAUs that the subscribers are able to reaffiliate with (indicated by a 1) and if those RAUs are unsaturated. If both conditions hold true then the RAU number is placed in the first location of the 1 by 6 matrix. This is accomplished for all possible RAUs in the column being tested. As each location in the 1 by 6 matrix is filled the variable I1 is incremented. This variable will be the divisor for the total number of subscribers to reaffiliate allowing an equal distribution of those subscribers among the available RAUs. A check is then made of the value of I1. If the value is zero this indicates that there are no available RAUs for the subscribers to reaffiliate with (yielding an unaffiliated subscribers case). In this case, matrix location M1(10,KA) is set to 1 indicating that this RAU has unaffiliated subscribers and the number of unaffiliated subscribers are entered into matrix location M2(9,KA) which is their parent RAU. SIMAN variable X(I+23) is also set to one indicating there are unaffiliated subscribers from this RAU. The SIMAN program maintains time persistent

statistics on these variables to provide the average saturation level of the RAU at the completion of the simulation.

If variable I1 was not equal to zero then as stated earlier, I1 becomes the divisor to distribute the reaffiliating subscribers. This is accomplished by the variable N2 being set equal to variable NA divided by I1. A check for any remainder is made by setting variable N3 equal to variable NA minus the quantity variable N2 multiplied by variable I1. A DO loop then assigns matrix locations M2(KA,RAU locations indicated in the 1 by 6 matrix) the number of subscribers currently there, plus the number of subscribers indicated in variable N2. A check is then made to determine if the remainder value N3 is not equal to zero. If this holds true then a DO loop distributes the remainder into the first and if necessary second available RAU depending on the value of the remainder (1 or 2). The subroutine SUB1 then returns to subroutine EVENT1.

Upon returning to EVENT1 the DO loop described earlier ensures that all subscribers currently affiliated with the saturating RAU appropriately reaffiliate. Upon completion of the total reaffiliation, two DO loops total up the number of subscribers affiliated with each RAU and enter those totals in matrix M2 along row 8. The DO loops further enter the total subscribers affiliated with each RAU in the X variable corresponding to the RAU number (i.e. X(1) for RAU1, X(2) for RAU2, etc.).

The next action that occurs is that X variables 31 through 36 are set equal to the proportion of the number of

subscribers affiliated with each RAU to the total number of network subscribers. This is necessary to allow the model to direct the appropriate "weight" of calls to those RAUs that have the most subscribers affilited. This is accomplished by using the SIMAN function SETP. This function is called for each component of parameter set 11 in order to update the parameter set to indicate the proportion of call arrivals that should be handled by each RAU. The subroutine then returns to the SIMAN submodel.

Subroutine EVENT2 is called when a RAU unsaturates. The first action that occurs in this subroutine is that the variable I is set equal to the value of the entity's attribute 9. This value can be 1 through 7 depending on which RAU just unsaturated. The matrix location indicating that the RAU is now unsaturated (M1(8,I)) is set to zero and the SIMAN X variable saturation flag for this RAU is set to zero. SIMAN variable X(37) is then decremented by 1/7th to provide total network statistics. The matrix location M2(10,I) (unaffiliated subscribers flag) is checked. If the value is 1 then the unaffiliated subscribers are placed back into an affiliated state with their parent RAU and the flag and the unaffiliated subscriber matrix location are set to 0. The SIMAN variable X(I+23) is also reset to 0 to enable collection of time persistent statistics on the saturation state of the RAU.

A DO loop then checks matrix M1 for all the locations that may hold subscribers that may have reaffiliated from this RAU. If the matrix M2 shows any of these subscribers,

variable S1 is incremented by the number of subscribers at each location and then that location is then set equal to zero. Next a DO loop checks each RAU that is capable of sending subscribers to the unsaturating RAU for unaffiliated subscribers. If there are any unaffiliated subscribers present, those subscribers are reaffiliated with the unsaturating RAU and the appropriate flags and matrix locations are reset to zero.

Matrix M2(I,I) is then incremented by the total number of subscribers held in variable S1. This matrix location now holds all subscribers that were capable of affiliating with the unsaturated RAU.

Two DO loops then total up the number of subscribers affiliated with each RAU and enter those totals in matrix M2 along row 8. The DO loops further enter the total for each RAU in an X variable corresponding to the RAU number (i.e., X(1) for RAU1, X(2) for RAU2, etc.). X variables 31 through 36 are set equal to proportion of the number of subscribers affiliated with each RAU to total network subscribers. Then the SIMAN function SETP is called for each value of parameter set 11 to update the parameter set to indicate the proportion of call arrivals that should be handled by each RAU. The subroutine then returns to the SIMAN submodel.

The subroutine PRIME establishes the two matrixes used by subroutine EVENT and SUB1 and initializes the values in each matrix. The data file BOX.DAT is used to provide the values for matrix M1 while matrix M2 is initialized directly from the subroutine.

The remaining subroutine, FUNCTION UR is necessary to cause the SIMAN program to seize the link resources specified by the value in attribute 4. This subroutine specifies to SIMAN a "user rule" that the desired value is held in attribute 4.

Program Code

The SIMAN model code and experimental frame listing for this simulation are provided in Appendix A. A variable description has been provided at the beginning of the model listing. The FORTRAN subroutine code listing is provided in Appendix B.

Validation and Verification

While performing the coding of the logic of the system and prior to making the experimental runs, the model must be verified and validated. Although verification and validation have similarities and the steps of each may be performed simultaneously, the difference exists in that verification relates to model operation while validation relates to how well the model represents the system under study. This section describes the verification and validation process for the model developed in this thesis.

Verification is the process of determining if the computer code truly represents the logic of the model. For the purposes of this research the verification process consisted of the following steps:

1. Conducting several structured "walk-throughs" of the model with persons not involved in the model development. These walk-throughs were the step by step manual execution of the program code using sample numbers to ensure the logic was correct. This ensured that the author had an outsiders perspective to evaluate the correctness of the program.

2. Documenting the code. By carefully explaining each step of the model and then having other programmers go through the program without disagreement regarding the explanations, the author was able to gain a great deal of confidence that the logic was correct.

3) By making extensive use of the "trace" feature of the SIMAN language. The trace feature allows the state of the system to be displayed after each event occurs to provide the user with a clear view of whether the model is behaving as intended.

4) By forcing events to occur. By setting input variables to different values it was easy to see that the model was operating as intended.

Validation is the overall process of comparing the model and its behavior to the real system and its behavior [58, p 383]. The work of Naylor and Finger provide an accepted method of validation for use in simulation [59]. They suggest a three step method to validate most simulation models. The three step approach was applied to the model developed in this thesis as follows:

1) Examine the model for "face validity". This was accomplished by a review of the model by persons knowledgeable about the system under study. The purpose of this review was to determine if the model was reasonable and to make suggestions or recommendations regarding changes if necessary. Additionally, several conversations were conducted with "experts" regarding both the MSE system and communications simulations. These conversations served to reinforce that the directions taken in the modeling process were correct.

2) Determine if the assumptions made are valid. The assumptions made in this model are structural assumptions. This type of assumption serves to simplify reality which in turn enables a complex system to be modeled. The assumptions made are stated throughout this work and have been explained. The assumptions made have been discussed with persons knowledgeable about the system and have been judged valid.

3) Determine how representative the simulation output data is to actual system data. This was not accomplished in that the total MSE system has not been fielded at this point in time and thus actual system data is not available. Therefore, in order to further validate the model the use of intuition was substituted and was used throughout the modeling process.

Based on the steps outlined above, a high degree of confidence was gained in the belief that this simulation model does in fact do what it is supposed to do and truly represents the MSRT-RAU communications system.

CHAPTER V

RESULTS

Simulation Output Analysis

All too often the major effort in a simulation project is devoted almost entirely to the study and model development of a system. The most common trap that modelers fall into is that of running a simulation for some arbitrary amount of time and then interpreting the simulation results as the "true" system response. When simulation inputs include one or more sources of random variables, the output will include random variation. Thus, simulation is actually a sampling experiment where the simulation output for a given set of pseudo random numbers is observed. As a sampling experiment, it is only appropriate that the results be interpreted within the framework of statistical analysis techniques.

The desired outputs of the model produced in this research are four network performance measures. These measures are the Network Grade of Service, the Network Saturation Level, the RAU Radio Utilizations and the Link Utilizations. Although all these performance measures are important, the two that are considered critical in terms of the research presented here are the Network Grade of Service and Saturation Level. These performance measures are to be presented for the entire network rather than by individual nodes. Each measure is presented in terms of a mean value μ.

The result of a set of simulation experiments is actually an estimate of the mean μ. Classic statistical procedures enable the analyst to determine an interval estimate of the mean from a given population in the form

$$\bar{X} - H \le \mu \le \bar{X} + H \tag{1}$$

with probability $(1 - \alpha)$, where $\bar{X}$ is the observed sample mean, H is the interval half width and $(1 - \alpha)$ is the confidence level of the interval. The interval half length, H, depends on the standard deviation, which if unknown, is a function of the mean response and the sample size. The method used to compute the standard deviation depends on whether the simulation is a terminating or non-terminating simulation.

There are basically two types of simulation models that can be studied, terminating and non-terminating. In a non-terminating simulation the subject of interest is to determine the steady state response of the system which is desired to be free from the effects of the initial conditions of the system. In terminating simulations the subject of interest is to determine the transient response of the system due to its starting conditions within a specified period of time or number of events [25].

Statistical analysis of terminating systems makes use of classical statistical analysis techniques based on Independent Identically Distributed (IID) observations. Since the run length of a terminating simulation models the finite operation of a system and is not subject to a modelers desire to change, the only way to increase the sample size is to

replicate the simulation run using different random numbers. To build a confidence interval for a terminating simulation a model is replicated N times. If all the observations X_i ($i=1,2,...,N$) are averages then the assumption of normality holds true based on the Central Limit Theorem. If X_i is the value of the response variable on the i-th run, then the sample mean is computed as

$$\bar{X} = \frac{\sum_{i=1}^{N} X_i}{N} . \qquad (2)$$

The sample variance is computed as

$$S^2(X) = \frac{\sum_{i=1}^{N} (X_i - \bar{X})^2}{N-1} . \qquad (3)$$

If the assumption that the X_i are independent is made, then the variance of the sample mean is computed as

$$S^2(\bar{X}) = \frac{S^2(X)}{N} . \qquad (4)$$

If the X_i are normally distributed, then a $(1-\alpha)$ confidence interval for $\mu = E(X)$ is given by

$$\bar{X} - S(\bar{X}) \cdot t_s \leq \mu \leq \bar{X} + S(\bar{X}) \cdot t_s \qquad (5)$$

where $t_s = t_{(N-1,\alpha/2)}$, which is the upper $\alpha/2$ point of the t-distribution with N-1 degrees of freedom [48, p 222-224].

Communications networks are generally considered to be terminating systems. This is because they usually fail to achieve a steady state and traffic load is highly dependent

on external events or the time of day. Although this is most often the case, the model developed in this thesis will be considered to be a non-terminating simulation. The reason for this is the desire to describe the worst case behavior of the system during the busy hour under expected loads. Therefore, each run of this model will be considered as generating many samples from periods of peak load conditions of typical busy hours. This behavior must be free of any initializing bias that results from starting the simulation from an empty and idle state.

Three generally accepted methods of dealing with the problem of initial bias in non-terminating simulations are given as follows [25]. The first method is to begin the simulation with the system already loaded. This initial loading represents starting the simulation at or near the steady state condition which in turn reduces the transient period. The second method is to run the simulation long enough to make any contribution to the output by the initial conditions insignificant. The third method is to discard the results from the initial transient phase. In practice, all three of the methods can be used simultaneously, although each method presents problems in terms of its implementation.

In terms of the first method, the question arises as to how much of a load should be applied to the simulation initially. In the second method, running the simulation for a long time period is not attractive because it wastes computer and analysist's time and cost. The third method's problem is determining how many observations should be

discarded. If too many observations are discarded, valuable data is lost, not to mention the waste of valuable computer time. If too few observations are discarded then the initial transient condition is still present and thus may bias the results.

In non-terminating simulations the ultimate goal is still to ensure a large enough sample size to utilize the classical statistical equations (1) through (5). If the simulation is replicated several times then each run provides an independent observation of the steady state condition and the classical equations apply. However, as in the case of this simulation where several experiments will be conducted, the number of runs can become very large and consume a great deal of time. Therefore, a single longer run is made and the biasing initial transient observations are discarded. The problem with this technique is that the observations are normally autocorrelated and the results cannot be summarized by equations (1) through (5).

An accepted method of overcoming autocorrelation from a single run is to divide the run into N subruns, termed batches [45, p 296]. The observations from the initial transient period must be discarded. Then the average of the observations in each batch is calculated as X_i and these averages can be used as samples in equations (1) through (5) to obtain an approximate confidence interval for μ. This method is called the method of batched means.

The method of batched means is intended to eliminate the initial biasing problem, however, the remaining batch means

are not independent random samples because the observations in each batch are correlated with observations in other batches. This correlation can have a serious effect on the validity of the variance estimator in Equation (4) and of the confidence interval specified in Equation (5). However, this can be considered a non-problem if the batch size is made large enough to make the correlation negligible. Pegden states that the method of batched means is probably the most useful in practice because it combines the advantages of the single run with the simplicity of analysis of the replications approach [48, p 229].

The SIMAN simulation language includes an Output Processor which aids in the interpretation of output from a simulation run. The output processor performs a procedure in the FILTER element whereby an appropriate batch size can be chosen for the output under analysis. The procedure is based on the work of Fishman [61]. Following the discarding of observations from the initial transient, the remaining observations are divided into batches of size N. The Von Neuman test is then used to determine an estimate of the correlation between adjacent batches. Then, based on the assumption that the correlation is normally distributed, a one or two sided hypothesis test is conducted to determine the independency between batches. Correlation is a function of covariance which is a function of the sample. Under the assumption of normality, if the covariance is equal to zero then the samples are considered independent. The population coefficient

of correlation ρ is related to the covariance and is defined as

$$\frac{Cov(X_1, X_2)}{\sigma_1 \sigma_2} \tag{6}$$

where σ_1 and σ_2 are the standard deviations of X_1 and X_2 respectively. The coefficient of correlation will only equal zero if the covariance equals zero implying independence of the samples. So, if the hypothesis test fails to reject the null hypothesis that the correlation is equal to zero then it cannot be concluded that the batches are independent. It can, however, be concluded that the evidence is not sufficient to conclude that the batches are correlated. The FILTER element produces an output file containing the means of the generated batches and a summary of the batching performed.

Experimental Design

The model developed in this research will be run once for each set of input parameters described in Table IV.

The run lengths of each experiment will be from 480 to 960 minutes long. These run lengths were chosen based on preliminary runs of the model to determine an appropriate length which allowed the system to achieve a steady state response. The statistics regarding the performance measures described above will be collected and reported in the SIMAN output summary document for each run. The Network Grade of Service and Saturation Level statistics will be written to an output file for each run. These output files will be input into the FILTER element of the SIMAN Output Processor to

determine an appropriate batch size and produce an output file of the batched means. These batched means will then be plotted using the SIMAN output element PLOT and a 95% confidence interval about the mean value will be constructed using the SIMAN output element INTERVALS. Finally, a plot of Grade of Service and Saturation Level versus the Mean Call Arrivals will be constructed to allow the Network Manager to determine control measures for different call arrival rates that may cause excessive saturation.

Table IV. Experimental Runs and Input Parameters

Simulation Run	Input Parameters	
	Call Holding Mean (minutes)	Call Creation Mean (minutes between arrivals)
1	5.0	0.125
2	5.0	0.25
3	5.0	0.28125
4	5.0	0.3125
5	5.0	0.3325
6	5.0	0.3437
7	5.0	0.345
8	5.0	0.35
9	5.0	0.375
10	3.0	0.125
11	3.0	0.15625
12	3.0	0.18755
13	3.0	0.21875
14	3.0	0.235
15	3.0	0.25
16	3.0	0.28125
17	3.0	0.3125
18	3.0	0.375

Analysis of Results

An example of the SIMAN Summary Reports that were generated by running the simulation is provided in Appendix C. Eighteen runs of the simulation were conducted using the input parameters specified above in Table IV. The experimentation consisted of varying the call arrival rates while maintaining two different average call holding times. The purpose of doing this was to determine the point or points where the network began to saturate to such an extent that the Network Grade of Service became unacceptable (less than 90%). For each run of the model, both the Network Saturation Level and Grade of Service values were written to an output file. The SIMAN Output Processor element FILTER was used to discard the initial transient observations and batch the data into an appropriate batch size so as to reduce any correlation between batches. The batched data was then plotted using the Output Processor PLOT element. The plots show the Network Saturation Level over time and GOS over time. A 95% confidence interval was established for each plotted statistic by using the output file produced from the FILTER element as the input to the INTERVALS element. An example of the plots, confidence intervals and summary of batching that was accomplished for each of the eighteen runs is shown in Appendix D.

Using the mean values of Grade of Service and Saturation Level generated for each of the mean call arrival rates by the INTERVALS element, the two graphs shown in Figures 10 and 11 were constructed. The graph in Figure 10 shows the

effects of different mean time between call arrivals on Grade of Service and Saturation Level for a call holding time that is exponentially distributed with a mean of 5.0 minutes. The graph in Figure 11 shows the same effects for a call holding time that is exponentially distributed with a mean of 3.0 minutes.

As can be seen in Figures 10 and 11, the model behaves similarly for the two different call holding times. Both sets of curves indicate that the network is self limiting in that at very high Saturation Levels the network does not fail, but continues to operate at very low Grade of Service levels. From this behavior it can be surmised that cascading saturation does not lead to total network failure. Both curves appear to show the network to operate in a somewhat bi-modal behavior. Either the network is not saturated and provides an acceptable Grade of Service level or the network is highly saturated and provides a very low Grade of Service level. Both Figures show a very steep transition point where a minute slowing of the call arrival rate results in the network changing from an unacceptable GOS level to an acceptable level. In Figure 10 nearly total network saturation exists for all mean call arrivals faster than 0.3325 minutes (approximately 181 calls per hour). Once calls begin arriving at a mean time of 0.3437 minutes (approximately 175 calls per hour) or slower, the network achieves a satisfactory GOS value of 92.7%. Figure 11 shows the same type of behavior, however calls can arrive at faster rates because of the lesser average call holding time. In Figure 11 the network

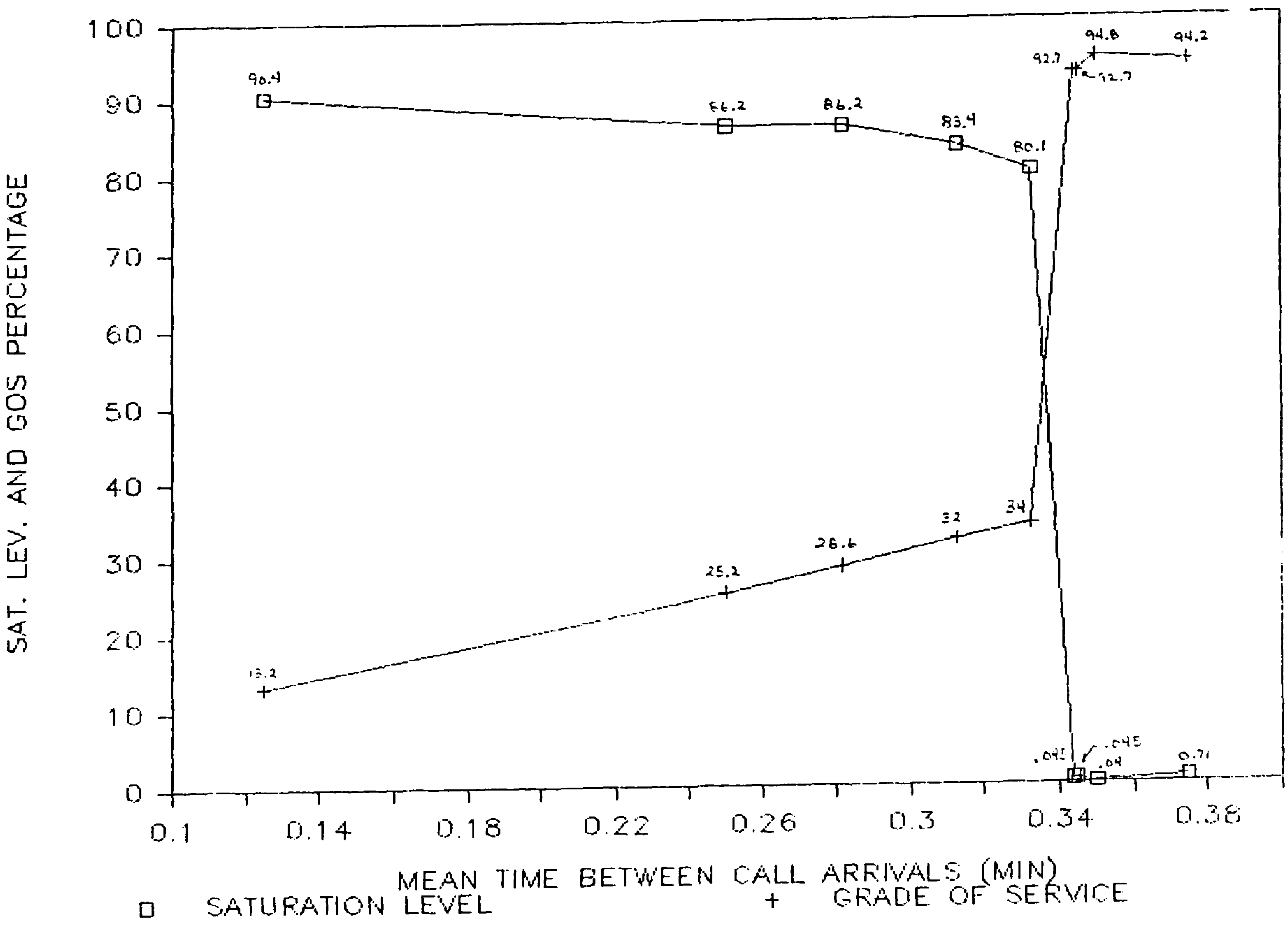

Figure 10. Graph of Saturation Level and Grade of Service versus Mean

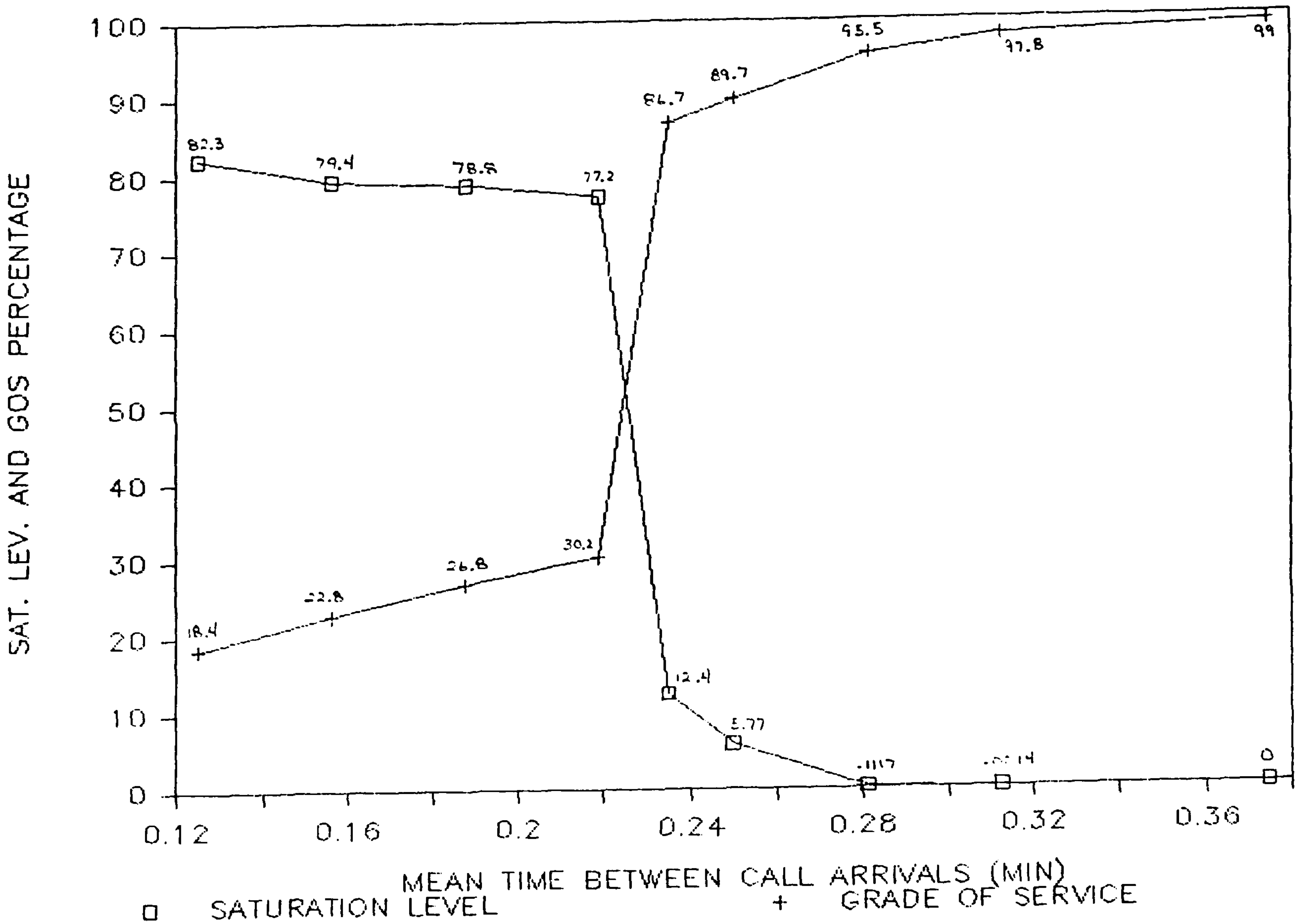

Figure 11. Graph of Saturation Level and Grade of Service versus Mean

exhibits very high saturation levels for calls arriving faster than a mean of 0.21875 minutes between arrivals (approximately 275 calls per hour) with corresponding low GOSlevels. A Call arrival rate of 0.235 minutes between arrivals (approximately 256 calls per hour) yields a GOS value of 86.7%. Slower arrival rates all yield acceptable GOS values (greater than 90%).

The remaining network performance measures provided in the model's output are shown in Table V.

Table V. Performance Measures

Link Usage Time by Link Number
Link Utilization by Link Number
Radio Utilization by RAU
Average Number of Affiliated Subscribers of each RAU
Average Saturation Level of Each RAU
Average Number of Unaffiliated Subscribers of each RAU
Successful calls handled by each RAU
Unsuccessful calls handled by each RAU
Number of times the marker signal was preempted at each RAU
Total successful calls handled by the Network
Number of Retries at each RAU
Total Call Demands handled by the Network

The average values for Link Utilization, Radio Utilization, Number of Affiliated Subscribers per RAU, and Number of Unaffiliated Subscribers per RAU have been extracted and are presented in Tables VI and VII. Table VI presents the average values from the runs with a mean call holding time of 5.0 minutes while Table VII presents the average values for the runs with a mean call holding time of 3.0 minutes. The Grand

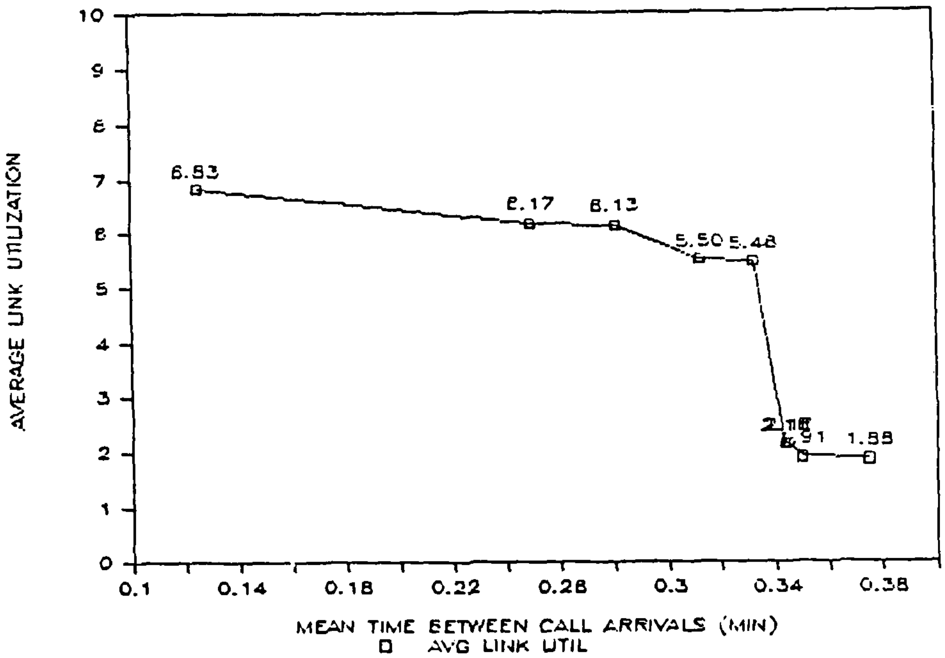

Figure 12. Graph of Average Link Utilization versus Mean Call Arrival Rate for a Call Holding Time of 5.0 Minutes

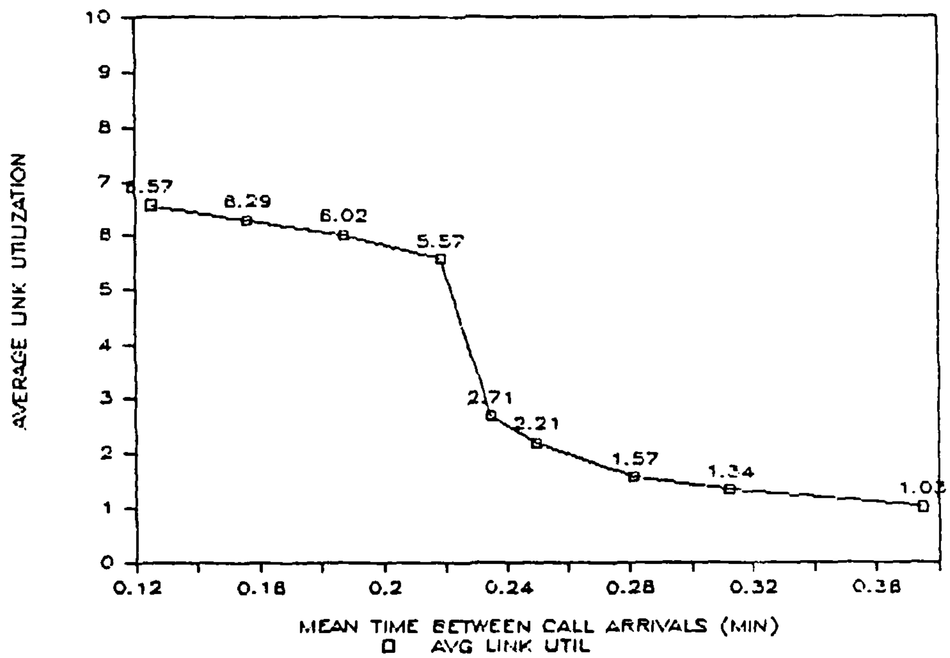

Figure 13. Graph of Average Link Utilization versus Mean Call Arrival Rate for a Call Holding Time of 3.0 Minutes

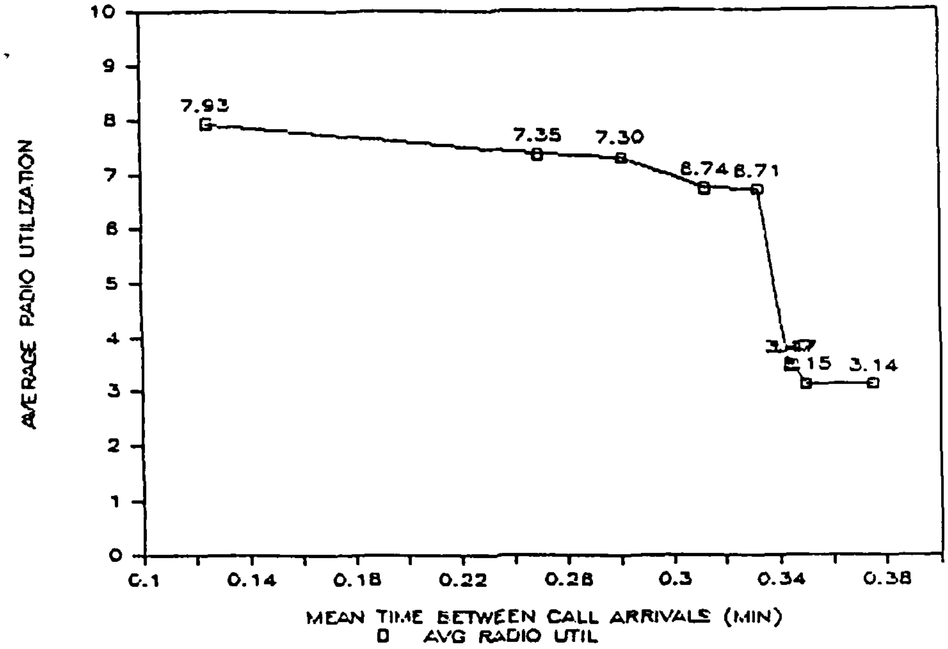

Figure 14. Graph of Average Radio Utilization versus Mean Call Arrival Rate for a Call Holding Time of 5.0 Minutes

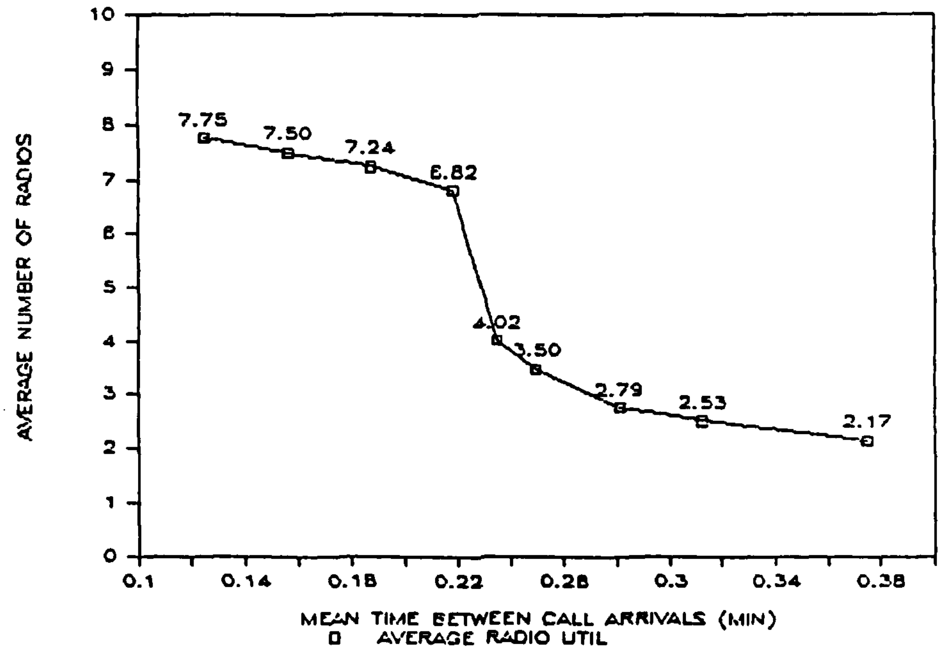

Figure 15. Graph of Average Radio Utilization versus Mean Call Arrival Rate for a Call Holding Time of 3.0 Minutes

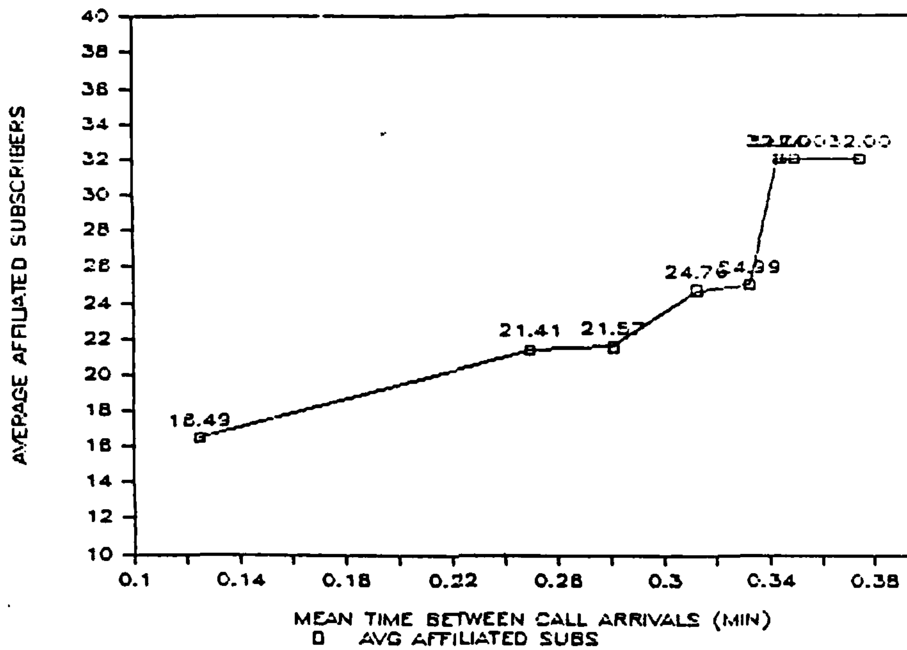

Figure 16. Graph of Average Number of Affiliated Subscribers per RAU versus Mean Call Arrival Rate for a Call Holding Time of 5.0 Minutes

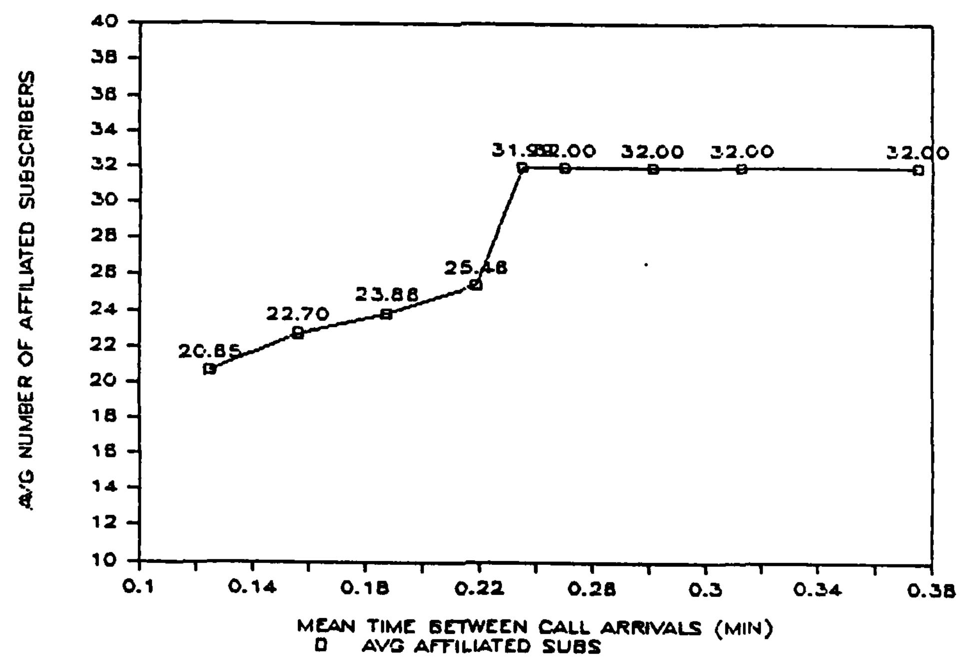

Figure 17. Graph of Average Number of Affiliated Subscribers per RAU versus Mean Call Arrival Rate for a Call Holding Time of 3.0 Minutes

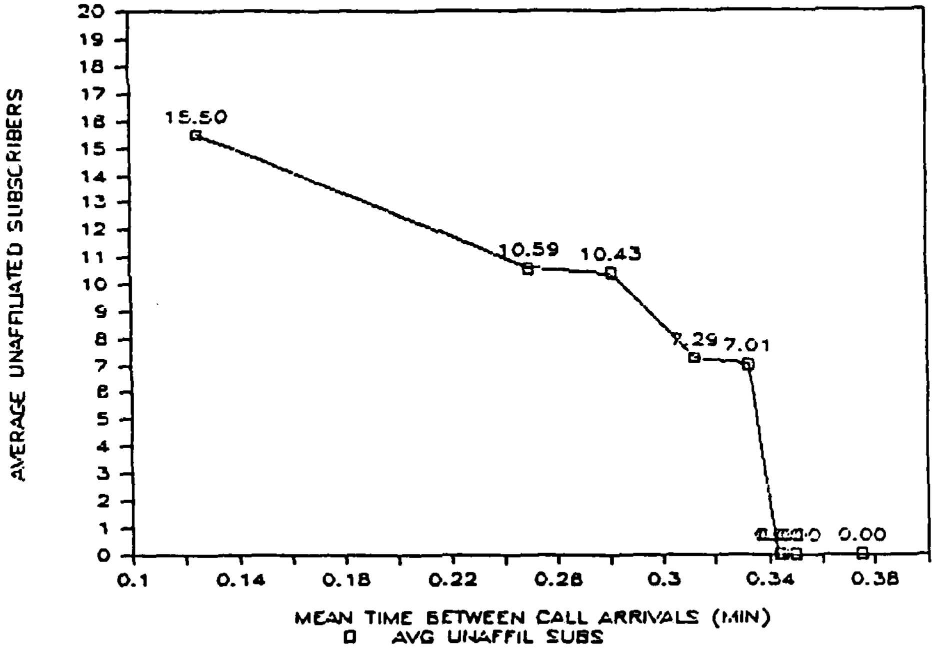

Figure 18. Graph of Average Number of Unaffiliated Subscribers per RAU versus Mean Call Arrival Rate for a Call Holding Time of 5.0 Minutes

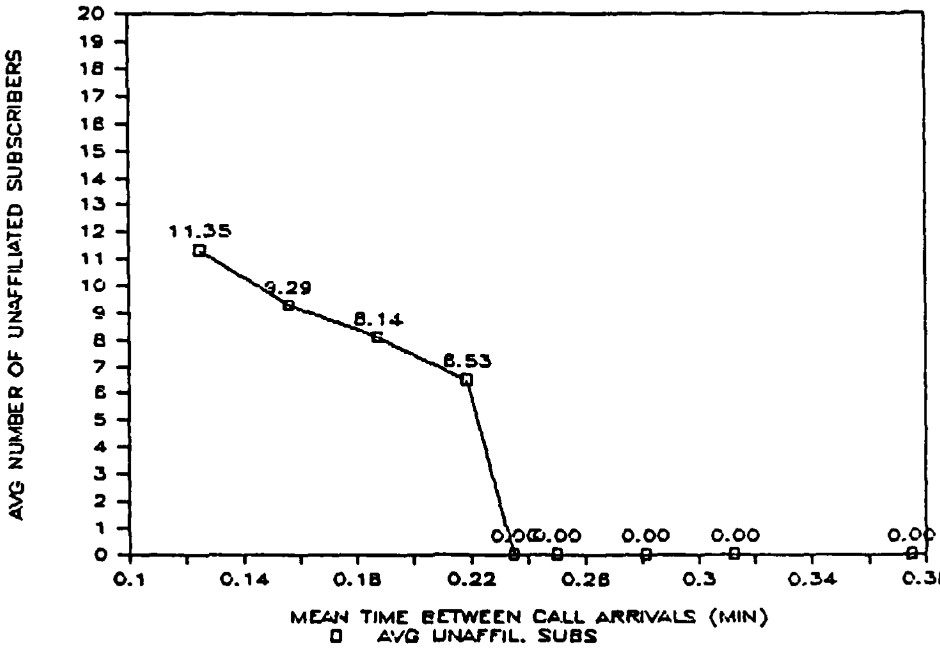

Figure 19. Graph of Average Number of Unaffiliated Subscribers per RAU versus Mean Call Arrival Rate for a Call Holding Time of 3.0 Minutes

Table VI. Extracted Averages of Performance Measures for a Mean Call Holding Time of 5.0 Minutes

	MEAN TIME BETWEEN CALL ARRIVALS IN MINUTES								
	0.125	0.25	0.28125	0.3125	0.3325	0.3437	0.345	0.35	0.375
AVERAGE LINK UTILIZATION BY LINK									
LINK 1	4.79	6.99	5.27	5.45	7.53	2.17	2.17	2.05	1.69
LINK 2	6.26	7.53	6.04	5.04	5.74	2.69	2.69	2.26	2.2
LINK 3	6.77	7.55	5.45	6.05	5.65	1.85	1.85	1.95	2.66
LINK 4	7.96	6.8	7.56	7.45	7.13	3.27	3.27	2.52	3.28
LINK 5	9.68	7.97	7.98	7.24	7.5	2.61	2.61	2.26	1.97
LINK 6	9.57	6.04	6.5	7.48	4	2.23	2.23	2.49	1.57
LINK 7	5.44	5.29	6.77	4.95	5.07	1.28	1.29	1.13	1.08
LINK 8	4.15	1.21	3.49	0.31	1.06	1.2	1.2	0.62	0.58
GRAND AVERAGE	6.8275	6.1725	6.1325	5.49625	5.46	2.1625	2.16375	1.91	1.87875
RADIO UTILIZATION BY RAU									
RAU 1	7.91	7.28	7.14	6.64	6.62	4.02	4.02	3.18	2.99
RAU 2	7.95	7.31	7.17	6.69	6.51	3.05	3.05	3.26	2.85
RAU 3	7.92	7.24	7.41	6.55	7.07	3.07	3.06	3.12	2.59
RAU 4	7.91	7.42	7.31	7.08	6.87	3.52	3.52	3.27	3.17
RAU 5	7.95	7.27	7.18	6.32	6.55	3.15	3.15	2.95	2.99
RAU 6	7.97	7.73	7.73	7.31	6.83	3.71	3.71	3.17	3.37
RAU 7	7.9	7.21	7.19	6.56	6.5	3.75	3.75	3.08	4.03
GRAND AVERAGE	7.93	7.351428	7.304285	6.735714	6.707142	3.467142	3.465714	3.147142	3.141428
AVERAGE AFFILIATED SUBSCRIBERS PER RAU									
RAU 1	16.17	21.16	19.16	23.61	24.32	31.73	31.73	32.01	32
RAU 2	15.68	21.35	21.02	23	25.17	32.09	32.09	31.96	32
RAU 3	15.6	20.81	21.24	26.37	22.55	32.11	32.11	32	32.01
RAU 4	20.03	24.41	25.71	25.72	25.82	32.15	32.15	32.01	32.24
RAU 5	15.38	21.4	21.82	28.06	25.57	32.04	32.04	32.01	32.23
RAU 6	15.87	19.49	20.58	21.19	25.9	31.98	31.98	32	32.2
RAU 7	16.73	21.23	21.46	24.96	25.59	31.91	31.91	32	31.33
GRAND AVERAGE	16.49428	21.40714	21.57	24.70142	24.98857	32.00142	32.00142	31.99857	32.00142
AVERAGE UNAFFILIATED SUBSCRIBERS PER RAU									
RAU 1	16.14	11	11.26	7.8	7.48	0	0	0	0
RAU 2	16.08	10.9	11.23	7.86	7.31	0	0	0	0
RAU 3	16.1	11.11	11.17	7.68	7.65	0	0	0	0
RAU 4	12.67	7.89	7.61	5.04	4.89	0	0	0	0
RAU 5	15.8	10.96	10.63	7.62	7.3	0	0	0	0
RAU 6	15.87	11.3	10.66	7.72	7.18	0	0	0	0
RAU 7	15.86	10.96	10.44	7.34	7.24	0	0	0	0
GRAND AVERAGE	15.50285	10.58857	10.42857	7.294285	7.007142	0	0	0	0

Table VII. Extracted Averages of Performance Measures for a Mean Call Holding Time of 3.0 Minutes

	MEAN TIME BETWEEN CALL ARRIVALS IN MINUTES								
	0.12500	0.15625	0.18750	0.21875	0.23500	0.25000	0.28125	0.31250	0.37500
AVERAGE LINK UTILIZATION BY LINK									
LINK 1	8.39000	8.03000	6.69000	6.56000	2.60000	2.22000	1.65000	1.27000	1.12000
LINK 2	8.50000	8.87000	6.90000	5.67000	3.53000	3.04000	2.33000	2.27000	1.33000
LINK 3	8.17000	7.47000	6.20000	7.57000	4.63000	3.21000	1.64000	1.47000	1.20000
LINK 4	8.06000	6.60000	8.19000	7.51000	3.42000	2.19000	1.97000	1.75000	1.44000
LINK 5	6.74000	6.10000	4.38000	7.26000	2.12000	2.24000	1.66000	1.39000	1.09000
LINK 6	3.62000	8.01000	3.35000	6.00000	3.32000	1.73000	1.50000	1.11000	1.03000
LINK 7	6.19000	5.01000	5.73000	2.16000	1.08000	1.93000	1.21000	0.96000	0.72000
LINK 8	2.92000	0.24000	6.74000	1.85000	0.98000	1.13000	0.57000	0.48000	0.27000
GRAND AVERAGE	6.57375	6.29125	6.02250	5.57250	2.71000	2.21125	1.56625	1.33750	1.02500
AVERAGE RADIO UTILIZATION BY RAU									
RAU 1	7.76000	7.51000	7.47000	6.79000	2.88000	3.45000	3.90000	2.34000	2.15000
RAU 2	7.72000	7.46000	7.01000	7.05000	3.07000	2.79000	2.72000	3.33000	2.08000
RAU 3	7.67000	7.59000	7.26000	6.77000	3.11000	3.22000	2.59000	2.42000	2.23000
RAU 4	7.74000	7.52000	7.25000	6.86000	5.05000	3.19000	2.60000	2.44000	2.16000
RAU 5	7.86000	7.46000	7.19000	6.62000	3.77000	3.34000	2.73000	2.46000	2.12000
RAU 6	7.83000	7.49000	7.25000	7.06000	6.34000	5.82000	2.61000	2.41000	2.31000
RAU 7	7.68000	7.46000	7.28000	6.56000	3.93000	2.67000	2.37000	2.32000	2.16000
GRAND AVERAGE	7.75143	7.49857	7.24429	6.81571	4.02143	3.49714	2.78857	2.53143	2.17286
AVERAGE AFFILIATED SUBSCRIBERS PER RAU									
RAU 1	20.46000	20.86000	21.26000	26.66000	32.97000	32.00000	31.92000	32.00000	32.00000
RAU 2	19.87000	20.13000	23.62000	23.88000	32.73000	32.03000	31.99000	31.99000	32.00000
RAU 3	20.47000	20.20000	23.14000	23.86000	36.36000	33.84000	32.03000	32.00000	32.00000
RAU 4	24.79000	29.62000	28.50000	28.23000	28.66000	33.82000	32.04000	32.00000	32.00000
RAU 5	19.23000	22.62000	23.28000	25.47000	33.03000	31.96000	32.01000	32.00000	32.00000
RAU 6	18.47000	23.27000	24.27000	23.40000	24.35000	26.43000	32.00000	32.00000	32.00000
RAU 7	21.25000	22.23000	22.93000	26.75000	35.86000	33.90000	32.00000	32.00000	32.00000
GRAND AVERAGE	20.64857	22.70429	23.85714	25.46429	31.99429	31.99714	31.99857	31.99857	32.00000
AVERAGE UNAFFILIATED SUBSCRIBERS PER RAU									
RAU 1	11.79000	10.15000	8.64000	7.02000	0.00000	0.00000	0.00000	0.00000	0.00000
RAU 2	11.83000	9.87000	8.68000	6.65000	0.00000	0.00000	0.00000	0.00000	0.00000
RAU 3	12.01000	9.73000	8.58000	6.96000	0.00000	0.00000	0.00000	0.00000	0.00000
RAU 4	8.58000	6.69000	5.72000	4.33000	0.00000	0.00000	0.00000	0.00000	0.00000
RAU 5	11.62000	9.66000	8.69000	6.98000	0.00000	0.00000	0.00000	0.00000	0.00000
RAU 6	11.84000	9.59000	8.36000	6.92000	0.00000	0.00000	0.00000	0.00000	0.00000
RAU 7	11.79000	9.34000	8.31000	6.88000	0.00000	0.00000	0.00000	0.00000	0.00000
GRAND AVERAGE	11.35143	9.29000	8.14000	6.53429	0.00000	0.00000	0.00000	0.00000	0.00000

Average values presented in the tables are an average of the averages.

The performance measures exhibited in the summary reports closely follow expected behavior. The graphs shown in Figures 12 through 19 were prepared to present the Grand Average values of the extracted performance measures for the two different mean call holding times. The graphs presented in Figures 12 and 13 show that the average Link Utilization figures show a much higher average value (at or above 50% of total available links) at those call arrival rates that cause the network to be saturated. The same behavior is evidenced for the average Radio Utilization per RAU (at or above 90% of available radios at each RAU) in Figures 14 and 15. All four figures show that at call arrival rates where there is little or no saturation, the Utilization figures are low. The graphs in Figures 16 and 17 show that the average number of subscribers affiliated with each RAU ranges from 15 to 25 at call arrival rates that cause high levels of network saturation and follows an increasing trend as the call arrival rate declines. The graphs in Figures 18 and 19 show that the average number of unaffiliated subscribers from each RAU ranges from 16 to 7 and follows a decreasing trend as the call arrival rate decreases. These statistics serve to support the relationship between Grade of Service and subscriber satisfaction. At high saturation levels, on average, 7 to 16 subscribers per RAU (50 to 112 of 224 network subscribers) will not be able to communicate. If

this is truly the case, it is assumed that subscriber satisfaction will be quite low.

From the SIMAN summary reports (an example is found in Appendix D), it was observed that the Saturation Level of each RAU closely parallels the Total Network Saturation Level for each run of the model. The remaining counter statistics which were provided in the summary reports served mainly to validate and verify the model, debug the model, and to support the four major performance measures presented thus far and will not be discussed further.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The purpose of this research was to develop a usable model that would determine the point at which saturation begins to effect nodal type networks and to assess the performance of nodal networks under various loading conditions using standard network performance measures. By virtue of the computer simulation model of the MSRT-RAU portion of the U.S. Army's MSE communications system presented in this thesis, the objective has been achieved.

From the COMM-Q model's output it can be seen that the saturation level of the nodal network simulated is highly dependent on the call arrival rate. There is a definite narrow transition range where the network shifts from a high saturation point and corresponding low Grade of Service to a low saturation point and a corresponding high (acceptable) Grade of Service. The call holding time has an effect on where the transition point occours along the mean time between arrivals scale. Provided the call arrival rate stays at some level below the transition point, both Radio and Link Utilization statistics are maintained at an average below 50%. Above the transition point, the Radio Utilization statistics average above 90%, while the Link Utilization statistics average above 50%. By using the interactive debugging capabilities of the SIMAN language, it was observed that cascading

saturation does in fact occur, however, it does not lead to network failure as was originally thought.

Based on the output analysis of the results of the simulation, it is strongly believed that RAU saturation will be a problem in MSRT-RAU portion of the MSE system. This opinion is predicated on personal intuition as a military communicator. If calls on the MSRT-RAU system average five minutes in length and arrive at approximately three per minute (0.3325 minute mean call arrival rate), the system will provide an average Grade of Service value of 34% with an average of 22% of the network subscribers not being able to communicate at any given time. Some may argue that MSRT users will have other means of communications at their disposal and thus the MSRT-RAU system will achieve call arrival rates as fast as those used in this simulation. This argument is countered by the belief that once subscribers discover the capabilities of the MSRT-RAU system, it will become the most popular communications means and thus the most heavily used.

The unfortunate insight gained from this simulation is that if call holding time is reduced the problem of saturation can be negated. However, based on the fact that the U.S. Army is a microcosm of American Society, there is probably little that can be done to reduce the amount of time subscribers spend on the telephone.

Extensions to the Research

Of prime interest to the author of this research is the validation of the model against actual MSRT-RAU behavior in

the field. The initial fielding of the MSE system will take place on Fort Hood, Texas with a divisional system being provided the 1st Cavalry Division sometime this fiscal year for testing and evaluation. It is hoped that a portion of a division exercise could be devoted to data collection specifically geared toward varying the call loading of the MSRT-RAU portion of the network. A scenario could be prepared where MSRT users are directed to make calls at specific times and of specified lengths. The network performance measures could be recorded and compared to this model's output.

Another extension to the research deals with expanding the model to include the dynamic features of mobile RAUs and the interference effects of radio waves. Instead of assuming that MSRTs can affiliate with only immediate neighboring RAUs, a submodel could be included that provides the probability of successful transmission-reception between RAUs and MSRT's based on distance and type of terrain. This could probably best be accomplished by incorporating the probability of connectivity into a FORTRAN subroutine called by the RAU submodels after a radio resource is seized. One possibility would be to base the subroutine on the work of Longely and Rice, whose model predicts the long term median radio transmission loss over irregular terrain [62].

One of the main goals at the start of this research was to make the model as general as possible in order to be able to apply it to any nodal type network. During the building of the model it was found that due to the specifics of the MSRT-RAU system, the model had to include routines or parts

that will not apply to other networks. However, the model is well documented and does represent a somewhat generalized model shell that could be modified to represent other nodal type networks. With some effort, the modifications could be made so that a user, via some sort of front end processor, could define node boundaries, the number of resources at each node, the number of customers affiliated with each node and the reaffiliation rules for saturated nodes. The user could then define the request for service rate and service rate by their appropriate distribution and parameters. The user would specify the time the model was to run and which of four generic network performance measures would be desired as output. The performance measures would be Saturation Level, Customer Satisfaction Level (corresponds to Grade of Service), Link Utilization and Resource Utilization. The major problem with the generalized shell concept is how to include special network protocols without requiring major program modifications.

A last extension to the research would be to animate the model. The SIMAN language has an animation package known as CINEMA, also by Systems Modeling Corporation that would be ideal to use to animate this research. This extension would probably be most useful if it were combined with the generalized shell approach. Animated simulation is highly useful to provide money controllers and non-technical decision makers the means to see a potentially costly situation prior to its actual occurrence. If a municipality's decision makers could actually see the effects of nodal saturation on Fire

Fighting or Emergency Services Facilities capabilities, perhaps a potentially dangerous situation could be avoided by adding or shifting resources throughout the network.

Implementation of the Results

A copy of this research and the model will be forwarded to the Systems Manager of the MSE program at the U.S. Army Signal Center to be used as a decision analysis tool in regards to the possible effects of RAU saturation on the dynamic modern battlefield.

APPENDICES

APPENDIX A

SIMAN MODEL AND EXPERIMENTAL FRAME LISTINGS

```
BEGIN;
;*****************************************************
;  MODEL LISTING OF THE MOBILE SUBSCRIBER RADIO
;  TERMINAL - REMOTE ACCESS UNIT SIMULATION
;*****************************************************
;
;VARIABLE AND ATTRIBUTE LISTING
;
;A(1)=INDICATES THE RAU THAT WILL HANDLE THE CALL
;A(2)=PRECEDENCE LEVEL OF INCOMING/OUTGOING CALL
;A(3)=HOLDING TIME OF INCOMING/OUTGOING CALL
;A(4)=LINK THE INCOMING/OUTGOING CALL WILL TRAVEL OVER
;A(5)=CARRYS ANY PREEMPTED CALL'S REMAINING DELAY TIME
;A(6)=INDICATES NUMBER OF RETRYS FOR A PARTICULAR CALL
;A(7)=INDICATES IF CALL IS INCOMING (1) OR OUTGOING (2)
;A(8)=UNIQUE NUMBER IDENTIFYING THE CALL DEMAND
;A(9)=CARRYS THE RAU NUMBER THAT SATURATES/UNSATURATES
;X(1)=NUMBER OF SUBSCRIBERS AFFILIATED WITH RAU 1
;X(2)=NUMBER OF SUBSCRIBERS AFFILIATED WITH RAU 2
;X(3)=NUMBER OF SUBSCRIBERS AFFILIATED WITH RAU 3
;X(4)=NUMBER OF SUBSCRIBERS AFFILIATED WITH RAU 4
;X(5)=NUMBER OF SUBSCRIBERS AFFILIATED WITH RAU 5
;X(6)=NUMBER OF SUBSCRIBERS AFFILIATED WITH RAU 6
;X(7)=NUMBER OF SUBSCRIBERS AFFILIATED WITH RAU 7
;X(8)=INDICATES WHICH RAU'S SUBSCRIBERS MUST RE-AFFILIATE
;X(9)=INDICATES RAU 1'S STATUS (1-SATURATED, 0-UNSAT)
;X(10)=INDICATES RAU 2'S STATUS (1-SATURATED, 0-UNSAT)
;X(11)=INDICATES RAU 3'S STATUS (1-SATURATED, 0-UNSAT)
;X(12)=INDICATES RAU 4'S STATUS (1-SATURATED, 0-UNSAT)
;X(13)=INDICATES RAU 5'S STATUS (1-SATURATED, 0-UNSAT)
;X(14)=INDICATES RAU 6'S STATUS (1-SATURATED, 0-UNSAT)
;X(15)=INDICATES RAU 7'S STATUS (1-SATURATED, 0-UNSAT)
;X(17)=NUMBER OF SATURATIONS AT RAU1
;X(18)=NUMBER OF SATURATIONS AT RAU2
;X(19)=NUMBER OF SATURATIONS AT RAU3
;X(20)=NUMBER OF SATURATIONS AT RAU4
;X(21)=NUMBER OF SATURATIONS AT RAU5
;X(22)=NUMBER OF SATURATIONS AT RAU6
;X(23)=NUMBER OF SATURATIONS AT RAU7
;X(24)=NUMBER OF SUBSCRIBERS UNAFFILIATED FROM RAU 1
;X(25)=NUMBER OF SUBSCRIBERS UNAFFILIATED FROM RAU 2
;X(26)=NUMBER OF SUBSCRIBERS UNAFFILIATED FROM RAU 3
;X(27)=NUMBER OF SUBSCRIBERS UNAFFILIATED FROM RAU 4
;X(28)=NUMBER OF SUBSCRIBERS UNAFFILIATED FROM RAU 5
;X(29)=NUMBER OF SUBSCRIBERS UNAFFILIATED FROM RAU 6
;X(30)=NUMBER OF SUBSCRIBERS UNAFFILIATED FROM RAU 7
;X(31)=PERCENTAGE OF TOTAL CALL DEMANDS DIRECTED TO RAU1
;X(32)=PERCENTAGE OF TOTAL CALL DEMANDS DIRECTED TO RAU2
;X(33)=PERCENTAGE OF TOTAL CALL DEMANDS DIRECTED TO RAU3
;X(34)=PERCENTAGE OF TOTAL CALL DEMANDS DIRECTED TO RAU4
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;X(35)=PERCENTAGE OF TOTAL CALL DEMANDS DIRECTED TO RAU5
;X(36)=PERCENTAGE OF TOTAL CALL DEMANDS DIRECTED TO RAU6
;X(37)=PERCENTAGE OF THE TOTAL NETWORK IN SATURATION
;X(38)=COUNTER TO GIVE EACH CALL AN IDENTIFYING NUMBER
;X(48)=TOTAL SUBSCRIBERS AFFILIATED WITH THE NETWORK
;X(49)=TOTAL SUBSCRIBERS AFFILIATED WITH THE NETWORK
;
;*******************************************************
;
;************************
;      MAIN MODEL
;************************
;
;CREATION OF CALL DEMANDS BY A POISSON DISTRIBUTION
;
        CREATE,1:NP(10,2);
;
        ASSIGN:X(38)=X(38)+1;COUNTER FOR CALL DEMAND NUMBER
        ASSIGN:A(8)=X(38); ASSIGN EACH CALL DEMAND A UNIQUE
;            IDENTIFYING NUMBER (USED FOR DEBUGGING PROGRAM)
;
;ASSIGN THE RAU NUMBER THAT THE CALL DEMAND EITHER
;ORIGINATED FROM OR IS DESTINED TO BY A DISCRETE
;PROBABILITY, ASSIGN THE CALL AS BEING EITHER
;INCOMING OR OUTGOING AND ASSIGN THE CALL'S
;PRECEDENCE, BOTH BY A DISCRETE PROBABILITY AND
;ASSIGN THE CALL'S LEGNTH BY AN EXPONENTIAL DISTRIBUTION.
;
        ASSIGN:A(1)=DP(11,1);  ASSIGN  RAU  TO  HANDLE  CALL
        ASSIGN:A(7)=DP(12,1); ASSIGN AS INCOMING/OUTGOING
        ASSIGN:A(2)=DP(1,1);  ASSIGN CALL PRECEDENCE
        ASSIGN:A(3)=EX(2,1);  ASSIGN CALL LENGTH
;
        COUNT:30;    COUNT THE TOTAL DEMANDS CREATED
;
;SEND THE CALL DEMAND TO THE APPROPRIATE RAU SUBMODEL
;BASED ON THE VALUE OF IT'S ATTRIBUTE 1.
;
        BRANCH,1:
           IF,A(1).EQ.1,RAU1:
           IF,A(1).EQ.2,RAU2:
           IF,A(1).EQ.3,RAU3:
           IF,A(1).EQ.4,RAU4:
           IF,A(1).EQ.5,RAU5:
           IF,A(1).EQ.6,RAU6:
           ELSE,RAU7;
;
;****************************
;    SUBMODEL FOR RAU 1
;****************************
;
;CHECK THE RAU'S SATURATION FLAG, IF IT IS EQUAL TO
;ONE THEN THIS DEMAND IS AN INCOMING CALL.  THE CALL
;IS DELAYED BY SOME SECONDS, THE RETRY COUNTER IS
;INCREMENTED BY ONE AND THE CALL THEN ENCOUNTERS A
```

```
;BRANCH WHICH CHECKS IF THE RETRY IS A THIRD ATTEMPT.
;IF IT IS THEN THE CALL IS DISPOSED OF.  OTHERWISE
;THE CALL IS COUNTED AS AN UNSUCCESSFUL CALL, COUNTED
;AS A RETRY, AND IS THEN ROUTED BACK TO THE BEGINNING
;OF THE SUBMODEL FOR THIS NODE.
;
RAU1         ASSIGN:A(4)=DP(3,1); ASSIGN LINK TO BE USED
             BRANCH,1:
                IF,X(9).EQ.1,HOLD11:
                ELSE,PASS1;
;
HOLD11       DELAY:EX(13,1);
             ASSIGN:A(6)=A(6)+1;
;
;CHECK TO SEE IF THIS CALL IS A SECOND RETRY, IF IT IS
;THEN COUNT IT AS AN UNSUCCESSFUL CALL, OTHERWISE ALLOW
;IT TO PROCESS ON.
;
             BRANCH,1:
                IF,A(6).GT.1,QUIT:
                ELSE,NXT1;
;
NXT1         COUNT:8;
             COUNT:23:NEXT(RAU1);
;
;CHECK TO SEE IF 5 OR MORE RADIOS ARE IN USE,
;IF SO GO TO PRESATURATION
;
PASS1     BRANCH,1:
             IF,NR(9).GE.5,PRESAT1:
             ELSE,CALLCOM1;
;
;IN PRESATURATION CHECK CALLS PRECEDENCE, IF
;IMMEDIATE OR FLASH, THE CALL CAN GO THROUGH,
;OTHERWISE CHECK TO SEE IF THE CALL IS
;AN OUTGOING CALL WHEREBY THE PRECEDENCE MAKES
;NO DIFFERENCE SO THE CALL IS ALLOWED TO CONTINUE.
;IF THE CALL IS AN INCOMING CALL THEN
;ROUTE IT TO BE COUNTED AS A RETRY AS DESCRIBED ABOVE.
;
PRESAT1   BRANCH,1:
             IF,A(3).GE.3,CHECK1:
             ELSE,OUTGO1;
;
OUTGO1    BRANCH,1:
             IF,A(7).EQ.2,CHECK1:
             ELSE,HOLD11;
;
;CHECK TO SEE IF THE BEACON BROADCASTING RADIO SHOULD
;BE BUMPED TO MAKE ROOM FOR THE EIGHTH SIMULTANEOUS
;CALL FROM THIS NODE
;
CHECK1    BRANCH,1:
             IF,NR(9).EQ.8,REAFFIL1:
             ELSE,CALLCOM1;
```

```
;
;THE CALL IS SERVICED BY ONE OF THE 8 AVAILABLE RADIOS
;AT THIS RAU, AND THE LINK SPECIFIED IN A(4) IS SEIZED.
;
CALLCOM1 QUEUE,1;
         SEIZE,1:RADIO1; SEIZE AN AVAILABLE RADIO
CALL1    QUEUE,22:MARK(5);
         SELECT,UR(1):LNK11:LNK12:LNK13:LNK14:LNK15:LNK16:
         LNK17:LNK18;
LNK11    SEIZE:LINK1,1:NEXT(HOLD1);
LNK12    SEIZE:LINK2,1:NEXT(HOLD1);
LNK13    SEIZE:LINK3,1:NEXT(HOLD1);
LNK14    SEIZE:LINK4,1:NEXT(HOLD1);
LNK15    SEIZE:LINK5,1:NEXT(HOLD1);
LNK16    SEIZE:LINK6,1:NEXT(HOLD1);
LNK17    SEIZE:LINK7,1:NEXT(HOLD1);
LNK18    SEIZE:LINK8,1:NEXT(HOLD1);
HOLD1    DELAY:A(3);  HOLD THE RADIO THE TIME OF THE CALL
         RELEASE:RADIO1; RELEASE THE RADIO
         BRANCH,1:
            IF,A(4).EQ.1,RLLNK11:
            IF,A(4).EQ.2,RLLNK12:
            IF,A(4).EQ.3,RLLNK13:
            IF,A(4).EQ.4,RLLNK14:
            IF,A(4).EQ.5,RLLNK15:
            IF,A(4).EQ.6,RLLNK16:
            IF,A(4).EQ.7,RLLNK17:
            ELSE,RLLNK18;
RLLNK11     RELEASE:LINK1,1:NEXT(TAL1);
RLLNK12     RELEASE:LINK2,1:NEXT(TAL1);
RLLNK13     RELEASE:LINK3,1:NEXT(TAL1);
RLLNK14     RELEASE:LINK4,1:NEXT(TAL1);
RLLNK15     RELEASE:LINK5,1:NEXT(TAL1);
RLLNK16     RELEASE:LINK6,1:NEXT(TAL1);
RLLNK17     RELEASE:LINK7,1:NEXT(TAL1);
RLLNK18     RELEASE:LINK8,1:NEXT(TAL1);
;
TAL1        TALLY:A(4),INT(5);
            KEEPS TRACK OF THE TIME THE LINK WAS USED
         COUNT:1;    COUNT THIS AS A SUCCESSFUL CALL
;
;CHECK IF THE FLAG INDICATING THAT THIS NODE WAS
;SATURATED WAS SET TO ONE, IF IT WAS NOW THERE ARE
;NO LONGER 8 RADIOS IN SERVICE AND ONE OF THE RADIOS
;CAN BROADCAST THE MARKER FREQUENCY.  IF THE
;FLAG WAS NOT SET GO TO LABEL FINISH.
;
         BRANCH,1:
            IF,X(9).EQ.1,UNREAFL1:
            ELSE,FINISH;
;
REAFFIL1 ASSIGN:X(8)=1;  SET THE FLAGS INDICATING
;                        THE NODE IS SATURATED
         ASSIGN:A(9)=1;
         QUEUE,15;
```

```
P1       PREEMPT,1:RADIO1,5,OUT1;
;        BUMP THE MARKER SIGNAL FOR A CALL
BUMP1    EVENT:1:NEXT(CALL1);
;CALL FORTRAN SUBROUTINE EVENT 1 WHICH CAUSES THE
;REMAINING SUBSCRIBERS TO AFFILIATE WITH A NEIGHBORING
;NODE BROADCASTING A MARKER SIGNAL.
;
UNREAFL1 ASSIGN:X(8)=11;  SET THE FLAG TO INDICATE THAT
;              THE NODE IS NO LONGER SATURATED.
         ASSIGN:A(9)=1;   SET FLAG TO TELL THE FORTRAN
;SUBROUTINE WHICH NODE UNSATS.
UNBUMP1  EVENT:2:NEXT(FINISH); CALL SUBROUTINE EVENT 2
;WHICH CAUSES SUBSCRIBERS TO REAFFILIATE WITH THEIR
;ORIGINAL RAU.
;
;****************************************
;SUB MODEL FOR MARKER FREQUENCY FOR RAU 1
;****************************************
;
         CREATE,1;
MARK1    QUEUE,8;
         SEIZE,2:RADIO1;
         DELAY:60;
         RELEASE:RADIO1:NEXT(MARK1);
;
;***********************
;    SUBMODEL FOR RAU 2
;***********************
;
;CHECK THE RAU'S SATURATION FLAG, IF IT IS EQUAL TO
;ONE THEN THIS DEMAND IS AN INCOMING CALL.  THE CALL
;IS DELAYED BY SOME SECONDS, THE RETRY COUNTER IS
;INCREMENTED BY ONE AND THE CALL THEN ENCOUNTERS A
;BRANCH WHICH CHECKS IF THE RETRY IS A THIRD ATTEMPT.
;IF IT IS THEN THE CALL IS DISPOSED OF.  OTHERWISE
;THE CALL IS COUNTED AS AN UNSUCCESSFUL CALL, COUNTED
;AS A RETRY, AND IS THEN ROUTED BACK TO THE BEGINNING
;OF THE SUBMODEL FOR THIS NODE.
;
RAU2     ASSIGN:A(4)=DP(4,1); ASSIGN LINK TO BE USED
         BRANCH,1:
            IF,X(10).EQ.1,HOLD22:
            ELSE,PASS2;
;
HOLD22      DELAY:EX(13,1);
            ASSIGN:A(6)=A(6)+1;
;
;CHECK TO SEE IF THIS CALL IS A SECOND RETRY, IF IT
;IS THEN COUNT IT AS AN UNSUCCESSFUL CALL, OTHERWISE
;ALLOW IT TO PROCESS ON.
;
            BRANCH,1:
               IF,A(6).GT.1,QUIT:
               ELSE,NXT2;
;
```

```
NXT2      COUNT:9;
          COUNT:24:NEXT(RAU2);
;
;CHECK TO SEE IF 5 OR MORE RADIOS ARE IN USE, IF SO
;GO TO PRESATURATION
;
PASS2     BRANCH,1:
             IF,NR(10).GE.5,PRESAT2:
             ELSE,CALLCOM2;
;
;IN PRESATURATION CHECK CALLS PRECEDENCE, IF
;IMMEDIATE OR FLASH, THE CALL CAN GO THROUGH,
;OTHERWISE CHECK TO SEE IF THE CALL IS
;AN OUTGOING CALL WHEREBY THE PRECEDENCE MAKES
;NO DIFFERENCE SO THE CALL IS ALLOWED TO CONTINUE.
;IF THE CALL IS AN INCOMING CALL THEN
;ROUTE IT TO BE COUNTED AS A RETRY AS DESCRIBED ABOVE.
;
PRESAT2   BRANCH,1:
             IF,A(3).GE.3,CHECK2:
             ELSE,OUTGO2;
;
OUTGO2    BRANCH,1:
             IF,A(7).EQ.2,CHECK2:
             ELSE,HOLD22;
;
;CHECK TO SEE IF THE BEACON BROADCASTING RADIO SHOULD
;BE BUMPED TO MAKE ROOM FOR THE EIGHTH SIMULTANEOUS
;CALL FROM THIS NODE
;
CHECK2    BRANCH,1:
             IF,NR(10).EQ.8,REAFFIL2:
             ELSE,CALLCOM2;
;
;THE CALL IS SERVICED BY ONE OF THE 8 AVAILABLE RADIOS
;AT THIS RAU, AND THE LINK SPECIFIED IN A(4) IS SEIZED.
;
CALLCOM2 QUEUE,2;
          SEIZE,1:RADIO2;
CALL2     QUEUE,23:MARK(5);
          SELECT,UR(1):LNK21:LNK22:LNK23:LNK24:LNK25:LNK26:
          LNK27:LNK28;
LNK21     SEIZE:LINK1,1:NEXT(HOLD2);
LNK22     SEIZE:LINK2,1:NEXT(HOLD2);
LNK23     SEIZE:LINK3,1:NEXT(HOLD2);
LNK24     SEIZE:LINK4,1:NEXT(HOLD2);
LNK25     SEIZE:LINK5,1:NEXT(HOLD2);
LNK26     SEIZE:LINK6,1:NEXT(HOLD2);
LNK27     SEIZE:LINK7,1:NEXT(HOLD2);
LNK28     SEIZE:LINK8,1:NEXT(HOLD2);
HOLD2     DELAY:A(3);  HOLD THE RADIO THE TIME OF THE CALL
          RELEASE:RADIO2; RELEASE THE RADIO
          BRANCH,1:
             IF,A(4).EQ.1,RLLNK21:
             IF,A(4).EQ.2,RLLNK22:
```

```
              IF,A(4).EQ.3,RLLNK23:
              IF,A(4).EQ.4,RLLNK24:
              IF,A(4).EQ.5,RLLNK25:
              IF,A(4).EQ.6,RLLNK26:
              IF,A(4).EQ.7,RLLNK27:
              ELSE,RLLNK28;
RLLNK21      RELEASE:LINK1,1:NEXT(TAL2);
RLLNK22      RELEASE:LINK2,1:NEXT(TAL2);
RLLNK23      RELEASE:LINK3,1:NEXT(TAL2);
RLLNK24      RELEASE:LINK4,1:NEXT(TAL2);
RLLNK25      RELEASE:LINK5,1:NEXT(TAL2);
RLLNK26      RELEASE:LINK6,1:NEXT(TAL2);
RLLNK27      RELEASE:LINK7,1:NEXT(TAL2);
RLLNK28      RELEASE:LINK8,1:NEXT(TAL2);
TAL2         TALLY:A(4),INT(5);
;KEEPS TRACK OF THE TIME THE LINK WAS USED
          COUNT:2;        COUNT THIS AS A SUCCESSFUL CALL
;
;CHECK IF THE FLAG INDICATING THAT THIS NODE WAS
;SATURATED WAS SET TO ONE, IF IT WAS NOW THERE
;ARE NO LONGER 8 RADIOS IN SERVICE
;AND ONE OF THE RADIOS CAN BROADCAST THE MARKER
;FREQUENCY.  IF THE FLAG WAS NOT SET GO TO LABEL FINISH.
;
          BRANCH,1:
             IF,X(10).EQ.1,UNREAFL2:
             ELSE,FINISH;
;
REAFFIL2 ASSIGN:X(8)=2;  SET THE FLAGS INDICATING THE
;                        NODE IS SATURATED
          ASSIGN:A(9)=2;
          QUEUE,16;
P2        PREEMPT,1:RADIO2,5,OUT2;  BUMP THE MARKER SIGNAL
;                                   FOR A CALL
BUMP2     EVENT:1:NEXT(CALL2);      CALL FORTRAN SUBROUTINE
;EVENT 1 WHICH CAUSES THE REMAINING SUBSCRIBERS TO AFFILIATE
;WITH A NEIGHBORING NODE BROADCASTING A MARKER SIGNAL.
;
UNREAFL2 ASSIGN:X(8)=12;  SET THE FLAGS TO INDICATE THAT
;THE NODE IS NO LONGER SATURATED.
          ASSIGN:A(9)=2;
UNBUMP2  EVENT:2:NEXT(FINISH);CALL SUBROUTINE EVENT 2
;WHICH CAUSES SUBSCRIBERS TO REAFFILIATE WITH THEIR
;ORIGINAL RAU.
;
;***************************************
;SUB MODEL FOR MARKER FREQUENCY FOR RAU 2
;***************************************
;
          CREATE,1;
MARK2     QUEUE,9;
          SEIZE,2:RADIO2;
          DELAY:60;
          RELEASE:RADIO2:NEXT(MARK2);
;
```

```
;**************************
;   SUBMODEL FOR RAU 3
;**************************
;
;CHECK THE RAU'S SATURATION FLAG, IF IT IS EQUAL TO
;ONE THEN THIS DEMAND IS AN INCOMING CALL.  THE CALL
;IS DELAYED BY SOME SECONDS, THE RETRY COUNTER IS
;INCREMENTED BY ONE AND THE CALL THEN ENCOUNTERS A
;BRANCH WHICH CHECKS IF THE RETRY IS A THIRD ATTEMPT.
;IF IT IS THEN THE CALL IS DISPOSED OF.  OTHERWISE
;THE CALL IS COUNTED AS AN UNSUCCESSFUL CALL, COUNTED
;AS A RETRY, AND IS THEN ROUTED BACK TO THE BEGINNING
;OF THE SUBMODEL FOR THIS NODE.
;
RAU3      ASSIGN:A(4)=DP(5,1);    ASSIGN LINK TO BE USED
          BRANCH,1:
             IF,X(11).EQ.1,HOLD33:
             ELSE,PASS3;
;
HOLD33       DELAY:EX(13,1);
             ASSIGN:A(6)=A(6)+1;
;
;CHECK TO SEE IF THIS CALL IS A SECOND RETRY, IF
;IT IS THEN COUNT IT AS AN UNSUCCESSFUL CALL,
;OTHERWISE ALLOW IT TO PROCESS ON.
;
             BRANCH,1:
                IF,A(6).GT.1,QUIT:
                ELSE,NXT3;
;
NXT3         COUNT:10;
             COUNT:25:NEXT(RAU3);
;
;CHECK TO SEE IF 5 OR MORE RADIOS ARE IN USE, IF
;SO GO TO PRESATURATION
;
PASS3     BRANCH,1:
             IF,NR(11).GE.5,PRESAT3:
             ELSE,CALLCOM3;
;
;IN PRESATURATION CHECK CALLS PRECEDENCE, IF
;IMMEDIATE OR FLASH, THE CALL CAN GO THROUGH,
;OTHERWISE CHECK TO SEE IF THE CALL IS
;AN OUTGOING CALL WHEREBY THE PRECEDENCE MAKES
;NO DIFFERENCE SO THE CALL IS ALLOWED TO CONTINUE.
;IF THE CALL IS AN INCOMING CALL THEN
;ROUTE IT TO BE COUNTED AS A RETRY AS DESCRIBED ABOVE.
;
PRESAT3   BRANCH,1:
             IF,A(3).GE.3,CHECK3:
             ELSE,OUTGO3;
;
OUTGO3    BRANCH,1:
             IF,A(7).EQ.2,CHECK3:
             ELSE,HOLD33;
```

```
;
;CHECK TO SEE IF THE BEACON BROADCASTING RADIO SHOULD
;BE BUMPED TO MAKE ROOM FOR THE EIGHTH SIMULTANEOUS CALL
;FROM THIS NODE
;
CHECK3   BRANCH,1:
             IF,NR(11).EQ.8,REAFFIL3:
             ELSE,CALLCOM3;
;
;THE CALL IS SERVICED BY ONE OF THE 8 AVAILABLE RADIOS
;AT THIS RAU, AND THE LINK SPECIFIED IN A(4) IS SEIZED.
;
CALLCOM3 QUEUE,3;
         SEIZE,1:RADIO3;
CALL3    QUEUE,24:MARK(5);
         SELECT,UR(1):LNK31:LNK32:LNK33:LNK34:LNK35:LNK36:
         LNK37:LNK38;
LNK31    SEIZE:LINK1,1:NEXT(HOLD3);
LNK32    SEIZE:LINK2,1:NEXT(HOLD3);
LNK33    SEIZE:LINK3,1:NEXT(HOLD3);
LNK34    SEIZE:LINK4,1:NEXT(HOLD3);
LNK35    SEIZE:LINK5,1:NEXT(HOLD3);
LNK36    SEIZE:LINK6,1:NEXT(HOLD3);
LNK37    SEIZE:LINK7,1:NEXT(HOLD3);
LNK38    SEIZE:LINK8,1:NEXT(HOLD3);
HOLD3    DELAY:A(3); HOLD THE RADIO THE TIME OF THE CALL
         RELEASE:RADIO3; RELEASE THE RADIO
         BRANCH,1:
             IF,A(4).EQ.1,RLLNK31:
             IF,A(4).EQ.2,RLLNK32:
             IF,A(4).EQ.3,RLLNK33:
             IF,A(4).EQ.4,RLLNK34:
             IF,A(4).EQ.5,RLLNK35:
             IF,A(4).EQ.6,RLLNK36:
             IF,A(4).EQ.7,RLLNK37:
             ELSE,RLLNK38;
RLLNK31     RELEASE:LINK1,1:NEXT(TAL3);
RLLNK32     RELEASE:LINK2,1:NEXT(TAL3);
RLLNK33     RELEASE:LINK3,1:NEXT(TAL3);
RLLNK34     RELEASE:LINK4,1:NEXT(TAL3);
RLLNK35     RELEASE:LINK5,1:NEXT(TAL3);
RLLNK36     RELEASE:LINK6,1:NEXT(TAL3);
RLLNK37     RELEASE:LINK7,1:NEXT(TAL3);
RLLNK38     RELEASE:LINK8,1:NEXT(TAL3);
TAL3        TALLY:A(4),INT(5);
;KEEPS TRACK OF THE TIME THE LINK WAS USED
         COUNT:3; COUNT THIS AS A SUCCESSFUL CALL
;
;CHECK IF THE FLAG INDICATING THAT THIS NODE WAS
;SATURATED WAS SET TO ONE, IF IT WAS NOW THERE
;ARE NO LONGER 8 RADIOS IN SERVICE
;AND ONE OF THE RADIOS CAN BROADCAST THE MARKER
;FREQUENCY.  IF THE FLAG WAS NOT SET GO TO LABEL FINISH.
;
         BRANCH,1:
```

```
            IF,X(11).EQ.1,UNREAFL3:
            ELSE,FINISH;
;
REAFFIL3 ASSIGN:X(8)=3;  SET THE FLAGS INDICATING THE
;                        NODE IS SATURATED
         ASSIGN:A(9)=3;
         QUEUE,21;
P3       PREEMPT,1:RADIO3,5,OUT3;  BUMP THE MARKER SIGNAL
;                                  FOR A CALL
BUMP3    EVENT:1:NEXT(CALL3);      CALL FORTRAN SUBROUTINE
;EVENT 1 WHICH CAUSES THE REMAINING SUBSCRIBERS TO
;AFFILIATE WITH A NEIGHBORING NODE BROADCASTING A MARKER
;SIGNAL.
;
UNREAFL3 ASSIGN:X(8)=13;  SET THE FLAGS TO INDICATE THAT
;THE NODE IS NO LONGER SATURATED.
         ASSIGN:A(9)=3;
UNBUMP3  EVENT:2:NEXT(FINISH);CALL SUBROUTINE EVENT 2
;WHICH CAUSES SUBSCRIBERS TO REAFFILIATE WITH THEIR
;ORIGINAL RAU.
;
;****************************************
;SUB MODEL FOR MARKER FREQUENCY FOR RAU 3
;****************************************
;
         CREATE,1;
MARK3    QUEUE,10;
         SEIZE,2:RADIO3;
         DELAY:60;
         RELEASE:RADIO3:NEXT(MARK3);
;
;*****************************
;    SUBMODEL FOR RAU 4
;*****************************
;
;CHECK THE RAU'S SATURATION FLAG, IF IT IS EQUAL TO
;ONE THEN THIS DEMAND IS AN INCOMING CALL.  THE CALL
;IS DELAYED BY SOME SECONDS, THE RETRY COUNTER IS
;INCREMENTED BY ONE AND THE CALL THEN ENCOUNTERS A
;BRANCH WHICH CHECKS IF THE RETRY IS A THIRD ATTEMPT.
;IF IT IS THEN THE CALL IS DISPOSED OF.  OTHERWISE
;THE CALL IS COUNTED AS AN UNSUCCESSFUL CALL, COUNTED
;AS A RETRY, AND IS THEN ROUTED BACK TO THE BEGINNING
;OF THE SUBMODEL FOR THIS NODE.
;
RAU4     ASSIGN:A(4)=DP(6,1); ASSIGN LINK TO BE USED
         BRANCH,1:
            IF,X(12).EQ.1,HOLD44:
            ELSE,PASS4;
;
HOLD44      DELAY:EX(13,1);
            ASSIGN:A(6)=A(6)+1;
;
;CHECK TO SEE IF THIS CALL IS A SECOND RETRY, IF IT
;IS THEN COUNT IT AS AN UNSUCCESSFUL CALL, OTHERWISE
```

```
;ALLOW IT TO PROCESS ON.
;
             BRANCH,1:
                IF,A(6).GT.1,QUIT:
                ELSE,NXT4;
;
NXT4         COUNT:11;
             COUNT:26:NEXT(RAU4);
;
;CHECK TO SEE IF 5 OR MORE RADIOS ARE IN USE, IF SO
;GO TO PRESATURATION
;
PASS4     BRANCH,1:
             IF,NR(12).GE.5,PRESAT4:
             ELSE,CALLCOM4;
;
;IN PRESATURATION CHECK CALLS PRECEDENCE, IF
;IMMEDIATE OR FLASH, THE CALL CAN GO THROUGH,
;OTHERWISE CHECK TO SEE IF THE CALL IS
;AN OUTGOING CALL WHEREBY THE PRECEDENCE MAKES
;NO DIFFERENCE SO THE CALL IS ALLOWED TO CONTINUE.
;IF THE CALL IS AN INCOMING CALL THEN
;ROUTE IT TO BE COUNTED AS A RETRY AS DESCRIBED ABOVE.
;
PRESAT4   BRANCH,1:
             IF,A(3).GE.3,CHECK4:
             ELSE,OUTGO4;
;
OUTGO4    BRANCH,1:
             IF,A(7).EQ.2,CHECK4:
             ELSE,HOLD44;
;
;CHECK TO SEE IF THE BEACON BROADCASTING RADIO SHOULD
;BE BUMPED TO MAKE ROOM FOR THE EIGHTH SIMULTANEOUS
;CALL FROM THIS NODE
;
CHECK4    BRANCH,1:
             IF,NR(12).EQ.8,REAFFIL4:
             ELSE,CALLCOM4;
;
;THE CALL IS SERVICED BY ONE OF THE 8 AVAILABLE RADIOS
;AT THIS RAU, AND THE LINK SPECIFIED IN A(4) IS SEIZED.
;
CALLCOM4  QUEUE,4;
          SEIZE,1:RADIO4;
CALL4     QUEUE,25:MARK(5);
          SELECT,UR(1):LNK41:LNK42:LNK43:LNK44:LNK45:LNK46:
          LNK47:LNK48;
LNK41     SEIZE:LINK1,1:NEXT(HOLD4);
LNK42     SEIZE:LINK2,1:NEXT(HOLD4);
LNK43     SEIZE:LINK3,1:NEXT(HOLD4);
LNK44     SEIZE:LINK4,1:NEXT(HOLD4);
LNK45     SEIZE:LINK5,1:NEXT(HOLD4);
LNK46     SEIZE:LINK6,1:NEXT(HOLD4);
LNK47     SEIZE:LINK7,1:NEXT(HOLD4);
```

```
LNK48     SEIZE:LINK8,1:NEXT(HOLD4);
HOLD4     DELAY:A(3); HOLD THE RADIO THE TIME OF THE CALL
          RELEASE:RADIO4; RELEASE THE RADIO
          BRANCH,1:
             IF,A(4).EQ.1,RLLNK41:
             IF,A(4).EQ.2,RLLNK42:
             IF,A(4).EQ.3,RLLNK43:
             IF,A(4).EQ.4,RLLNK44:
             IF,A(4).EQ.5,RLLNK45:
             IF,A(4).EQ.6,RLLNK46:
             IF,A(4).EQ.7,RLLNK47:
             ELSE,RLLNK48;
RLLNK41     RELEASE:LINK1,1:NEXT(TAL4);
RLLNK42     RELEASE:LINK2,1:NEXT(TAL4);
RLLNK43     RELEASE:LINK3,1:NEXT(TAL4);
RLLNK44     RELEASE:LINK4,1:NEXT(TAL4);
RLLNK45     RELEASE:LINK5,1:NEXT(TAL4);
RLLNK46     RELEASE:LINK6,1:NEXT(TAL4);
RLLNK47     RELEASE:LINK7,1:NEXT(TAL4);
RLLNK48     RELEASE:LINK8,1:NEXT(TAL4);
TAL4        TALLY:A(4),INT(5);
;KEEPS TRACK OF THE TIME THE LINK WAS USED
          COUNT:4;  COUNT THIS AS A SUCCESSFUL CALL
;
;CHECK IF THE FLAG INDICATING THAT THIS NODE WAS
;SATURATED WAS SET TO ONE, IF IT WAS NOW THERE
;ARE NO LONGER 8 RADIOS IN SERVICE
;AND ONE OF THE RADIOS CAN BROADCAST THE MARKER
;FREQUENCY.  IF THE FLAG WAS NOT SET GO TO LABEL FINISH.
;
          BRANCH,1:
             IF,X(12).EQ.1,UNREAFL4:
             ELSE,FINISH;
;
REAFFIL4 ASSIGN:X(8)=4;   SET THE FLAGS INDICATING THE
;                         NODE IS SATURATED
          ASSIGN:A(9)=4;
          QUEUE,17;
P4        PREEMPT,1:RADIO4,5,OUT4;  BUMP THE MARKER
;                                   SIGNAL FOR A CALL
BUMP4     EVENT:1:NEXT(CALL4); CALL FORTRAN SUBROUTINE
;EVENT 1 WHICH CAUSES THE REMAINING SUBSCRIBERS TO
;AFFILIATE WITH A NEIGHBORING NODE BROADCASTING A
;MARKER SIGNAL.
;
UNREAFL4 ASSIGN:X(8)=14;  SET THE FLAGS TO INDICATE
;THAT THE NODE IS NO LONGER SATURATED.
          ASSIGN:A(9)=4;
UNBUMP4  EVENT:2:NEXT(FINISH);  CALL SUBROUTINE EVENT
;2 WHICH CAUSES SUBSCRIBERS TO REAFFILIATE WITH THEIR
;ORIGINAL RAU.
;
;****************************************
;SUB MODEL FOR MARKER FREQUENCY FOR RAU 4
;****************************************
```

```
;
        CREATE,1;
MARK4   QUEUE,11;
        SEIZE,2:RADIO4;
        DELAY:60;
        RELEASE:RADIO4:NEXT(MARK4);
;
;**************************
;    SUBMODEL FOR RAU 5
;**************************
;
;CHECK THE RAU'S SATURATION FLAG, IF IT IS EQUAL TO
;ONE THEN THIS DEMAND IS AN INCOMING CALL.  THE CALL
;IS DELAYED BY SOME SECONDS, THE RETRY COUNTER IS
;INCREMENTED BY ONE AND THE CALL THEN ENCOUNTERS A
;BRANCH WHICH CHECKS IF THE RETRY IS A THIRD ATTEMPT.
;IF IT IS THEN THE CALL IS DISPOSED OF.  OTHERWISE
;THE CALL IS COUNTED AS AN UNSUCCESSFUL CALL, COUNTED
;AS A RETRY, AND IS THEN ROUTED BACK TO THE BEGINNING
;OF THE SUBMODEL FOR THIS NODE.
;
RAU5    ASSIGN:A(4)=DP(7,1); ASSIGN LINK TO BE USED
        BRANCH,1:
           IF,X(13).EQ.1,HOLD55:
           ELSE,PASS5;
;
HOLD55     DELAY:EX(13,1);
           ASSIGN:A(6)=A(6)+1;
;
;CHECK TO SEE IF THIS CALL IS A SECOND RETRY, IF
;IT IS THEN COUNT IT AS AN UNSUCCESSFUL CALL,
;OTHERWISE ALLOW IT TO PROCESS ON.
;
           BRANCH,1:
              IF,A(6).GT.1,QUIT:
              ELSE,NXT5;
;
NXT5       COUNT:12;
           COUNT:27:NEXT(RAU5);
;
;CHECK TO SEE IF 5 OR MORE RADIOS ARE IN USE,
;IF SO GO TO PRESATURATION
;
PASS5   BRANCH,1:
           IF,NR(13).GE.5,PRESAT5:
           ELSE,CALLCOM5;
;
;IN PRESATURATION CHECK CALLS PRECEDENCE, IF
;IMMEDIATE OR FLASH, THE CALL CAN GO THROUGH,
;OTHERWISE CHECK TO SEE IF THE CALL IS
;AN OUTGOING CALL WHEREBY THE PRECEDENCE MAKES
;NO DIFFERENCE SO THE CALL IS ALLOWED TO CONTINUE.
;IF THE CALL IS AN INCOMING CALL THEN
;ROUTE IT TO BE COUNTED AS A RETRY AS DESCRIBED ABOVE.
;
```

```
PRESAT5  BRANCH,1:
             IF,A(3).GE.3,CHECK5:
             ELSE,OUTGO5;
;
OUTGO5   BRANCH,1:
             IF,A(7).EQ.2,CHECK5:
             ELSE,HOLD55;
;
;CHECK TO SEE IF THE BEACON BROADCASTING RADIO
;SHOULD BE BUMPED TO MAKE ROOM FOR THE EIGHTH
;SIMULTANEOUS CALL FROM THIS NODE
;
CHECK5   BRANCH,1:
             IF,NR(13).EQ.8,REAFFIL5:
             ELSE,CALLCOM5;
;
;THE CALL IS SERVICED BY ONE OF THE 8 AVAILABLE
;RADIOS AT THIS RAU, AND THE LINK SPECIFIED
;IN A(4) IS SEIZED.
;
CALLCOM5 QUEUE,5;
         SEIZE,1:RADIO5;
CALL5    QUEUE,26:MARK(5);
         SELECT,UR(1):LNK51:LNK52:LNK53:LNK54:LNK55:LNK56:
         LNK57:LNK58;
LNK51    SEIZE:LINK1,1:NEXT(HOLD5);
LNK52    SEIZE:LINK2,1:NEXT(HOLD5);
LNK53    SEIZE:LINK3,1:NEXT(HOLD5);
LNK54    SEIZE:LINK4,1:NEXT(HOLD5);
LNK55    SEIZE:LINK5,1:NEXT(HOLD5);
LNK56    SEIZE:LINK6,1:NEXT(HOLD5);
LNK57    SEIZE:LINK7,1:NEXT(HOLD5);
LNK58    SEIZE:LINK8,1:NEXT(HOLD5);
HOLD5    DELAY:A(3); HOLD THE RADIO THE TIME OF THE CALL
         RELEASE:RADIO5; RELEASE THE RADIO
         BRANCH,1:
             IF,A(4).EQ.1,RLLNK51:
             IF,A(4).EQ.2,RLLNK52:
             IF,A(4).EQ.3,RLLNK53:
             IF,A(4).EQ.4,RLLNK54:
             IF,A(4).EQ.5,RLLNK55:
             IF,A(4).EQ.6,RLLNK56:
             IF,A(4).EQ.7,RLLNK57:
             ELSE,RLLNK58;
RLLNK51     RELEASE:LINK1,1:NEXT(TAL5);
RLLNK52     RELEASE:LINK2,1:NEXT(TAL5);
RLLNK53     RELEASE:LINK3,1:NEXT(TAL5);
RLLNK54     RELEASE:LINK4,1:NEXT(TAL5);
RLLNK55     RELEASE:LINK5,1:NEXT(TAL5);
RLLNK56     RELEASE:LINK6,1:NEXT(TAL5);
RLLNK57     RELEASE:LINK7,1:NEXT(TAL5);
RLLNK58     RELEASE:LINK8,1:NEXT(TAL5);
TAL5        TALLY:A(4),INT(5);
;KEEPS TRACK OF THE TIME THE LINK WAS USED
            COUNT:5;   COUNT THIS AS A SUCCESSFUL CALL
```

```
;
;CHECK IF THE FLAG INDICATING THAT THIS NODE WAS
;SATURATED WAS SET TO ONE, IF IT WAS NOW THERE
;ARE NO LONGER 8 RADIOS IN SERVICE
;AND ONE OF THE RADIOS CAN BROADCAST THE MARKER
;FREQUENCY.  IF THE FLAG WAS NOT SET GO TO LABEL FINISH.
;
         BRANCH,1:
            IF,X(13).EQ.1,UNREAFL5:
            ELSE,FINISH;
;
REAFFIL5 ASSIGN:X(8)=5;  SET THE FLAG INDICATING
;                        THE NODE IS SATURATED
         ASSIGN:A(9)=5;
         QUEUE,18;
P5       PREEMPT,1:RADIO5,5,OUT5;  BUMP THE MARKER
;                                  SIGNAL FOR A CALL
BUMP5    EVENT:1:NEXT(CALL5);      CALL FORTRAN
;SUBROUTINE EVENT 1 WHICH CAUSES THE REMAINING
;SUBSCRIBERS TO AFFILIATE WITH A NEIGHBORING NODE
;BROADCASTING A MARKER SIGNAL.
;
UNREAFL5 ASSIGN:X(8)=15;  SET THE FLAGS TO INDICATE
;THAT THE NODE IS NO LONGER SATURATED.
         ASSIGN:A(9)=5;
UNBUMP5  EVENT:2:NEXT(FINISH);  CALL SUBROUTINE EVENT
;2 WHICH CAUSES SUBSCRIBERS TO REAFFILIATE WITH THEIR
;ORIGINAL RAU.
;
;****************************************
;SUB MODEL FOR MARKER FREQUENCY FOR RAU 5
;****************************************
;
         CREATE,1;
MARK5    QUEUE,12;
         SEIZE,2:RADIO5;
         DELAY:60;
         RELEASE:RADIO5:NEXT(MARK5);
;
;*****************************
;     SUBMODEL FOR RAU 6
;*****************************
;
;CHECK THE RAU'S SATURATION FLAG, IF IT IS EQUAL TO
;ONE THEN THIS DEMAND IS AN INCOMING CALL.  THE CALL
;IS DELAYED BY SOME SECONDS, THE RETRY COUNTER IS
;INCREMENTED BY ONE AND THE CALL THEN ENCOUNTERS A
;BRANCH WHICH CHECKS IF THE RETRY IS A THIRD ATTEMPT.
;IF IT IS THEN THE CALL IS DISPOSED OF.  OTHERWISE
;THE CALL IS COUNTED AS AN UNSUCCESSFUL CALL, COUNTED
;AS A RETRY, AND IS THEN ROUTED BACK TO THE BEGINNING
;OF THE SUBMODEL FOR THIS NODE.
;
RAU6     ASSIGN:A(4)=DP(8,1); ASSIGN LINK TO BE USED
         BRANCH,1:
```

```
              IF,X(14).EQ.1,HOLD66:
              ELSE,PASS6;
;
HOLD66        DELAY:EX(13,1);
              ASSIGN:A(6)=A(6)+1;
;
;CHECK TO SEE IF THIS CALL IS A SECOND RETRY, IF
;IT IS THEN COUNT IT AS AN UNSUCCESSFUL CALL,
;OTHERWISE ALLOW IT TO PROCESS ON.
;
              BRANCH,1:
                 IF,A(6).GT.1,QUIT:
                 ELSE,NXT6;
;
NXT6          COUNT:13;
              COUNT:28:NEXT(RAU6);
;
;CHECK TO SEE IF 5 OR MORE RADIOS ARE IN USE,
;IF SO GO TO PRESATURATION
;
PASS6     BRANCH,1:
             IF,NR(14).GE.5,PRESAT6:
             ELSE,CALLCOM6;
;
;IN PRESATURATION CHECK CALLS PRECEDENCE, IF
;IMMEDIATE OR FLASH, THE CALL CAN GO THROUGH,
;OTHERWISE CHECK TO SEE IF THE CALL IS
;AN OUTGOING CALL WHEREBY THE PRECEDENCE MAKES
;NO DIFFERENCE SO THE CALL IS ALLOWED TO CONTINUE.
;IF THE CALL IS AN INCOMING CALL THEN
;ROUTE IT TO BE COUNTED AS A RETRY AS DESCRIBED ABOVE.
;
PRESAT6   BRANCH,1:
             IF,A(3).GE.3,CHECK6:
             ELSE,OUTGO6;
;
OUTGO6    BRANCH,1:
             IF,A(7).EQ.2,CHECK6:
             ELSE,HOLD66;
;
;CHECK TO SEE IF THE BEACON BROADCASTING RADIO SHOULD
;BE BUMPED TO MAKE ROOM FOR THE EIGHTH SIMULTANEOUS
;CALL FROM THIS NODE
;
CHECK6    BRANCH,1:
             IF,NR(14).EQ.8,REAFFIL6:
             ELSE,CALLCOM6;
;
;THE CALL IS SERVICED BY ONE OF THE 8 AVAILABLE RADIOS
;AT THIS RAU, AND THE LINK SPECIFIED IN A(4) IS SEIZED.
;
CALLCOM6 QUEUE,6;
         SEIZE,1:RADIO6;
CALL6    QUEUE,27:MARK(5);
         SELECT,UR(1):LNK61:LNK62:LNK63:LNK64:LNK65:LNK66:
```

```
          LNK67:LNK68;
LNK61     SEIZE:LINK1,1:NEXT(HOLD6);
LNK62     SEIZE:LINK2,1:NEXT(HOLD6);
LNK63     SEIZE:LINK3,1:NEXT(HOLD6);
LNK64     SEIZE:LINK4,1:NEXT(HOLD6);
LNK65     SEIZE:LINK5,1:NEXT(HOLD6);
LNK66     SEIZE:LINK6,1:NEXT(HOLD6);
LNK67     SEIZE:LINK7,1:NEXT(HOLD6);
LNK68     SEIZE:LINK8,1:NEXT(HOLD6);
HOLD6     DELAY:A(3); HOLD THE RADIO THE TIME OF THE CALL
          RELEASE:RADIO6; RELEASE THE RADIO
          BRANCH,1:
             IF,A(4).EQ.1,RLLNK61:
             IF,A(4).EQ.2,RLLNK62:
             IF,A(4).EQ.3,RLLNK63:
             IF,A(4).EQ.4,RLLNK64:
             IF,A(4).EQ.5,RLLNK65:
             IF,A(4).EQ.6,RLLNK66:
             IF,A(4).EQ.7,RLLNK67:
             ELSE,RLLNK68;
RLLNK61     RELEASE:LINK1,1:NEXT(TAL6);
RLLNK62     RELEASE:LINK2,1:NEXT(TAL6);
RLLNK63     RELEASE:LINK3,1:NEXT(TAL6);
RLLNK64     RELEASE:LINK4,1:NEXT(TAL6);
RLLNK65     RELEASE:LINK5,1:NEXT(TAL6);
RLLNK66     RELEASE:LINK6,1:NEXT(TAL6);
RLLNK67     RELEASE:LINK7,1:NEXT(TAL6);
RLLNK68     RELEASE:LINK8,1:NEXT(TAL6);
TAL6        TALLY:A(4),INT(5);
;KEEPS TRACK OF THE TIME THE LINK WAS USED
         COUNT:6; COUNT THIS AS A SUCCESSFUL CALL
;
;CHECK IF THE FLAG INDICATING THAT THIS NODE WAS
;SATURATED WAS SET TO ONE, IF IT WAS NOW THERE
;ARE NO LONGER 8 RADIOS IN SERVICE
;AND ONE OF THE RADIOS CAN BROADCAST THE MARKER
;FREQUENCY.  IF THE FLAG WAS NOT SET GO TO LABEL FINISH.
;
         BRANCH,1:
            IF,X(14).EQ.1,UNREAFL6:
            ELSE,FINISH;
;
REAFFIL6 ASSIGN:X(8)=6;  SET THE FLAGS INDICATING THE
;                        NODE IS SATURATED
         ASSIGN:A(9)=6;
         QUEUE,19;
P6       PREEMPT,1:RADIO6,5,OUT6;  BUMP THE MARKER
;                                  SIGNAL FOR A CALL
BUMP6    EVENT:1:NEXT(CALL6);      CALL FORTRAN SUBROUTINE
;EVENT 1 WHICH CAUSES THE REMAINING SUBSCRIBERS TO
;AFFILIATE WITH A NEIGHBORING NODE BROADCASTING A MARKER
;SIGNAL.
;
UNREAFL6 ASSIGN:X(8)=16;  SET THE FLAGS TO INDICATE
;THAT THE NODE IS NO LONGER SATURATED.
```

```
        ASSIGN:A(9)=6;
UNBUMP6 EVENT:2:NEXT(FINISH);  CALL SUBROUTINE EVENT 2
;WHICH CAUSES SUBSCRIBERS TO REAFFILIATE WITH THEIR
;ORIGINAL RAU.
;
;****************************************
;SUB MODEL FOR MARKER FREQUENCY FOR RAU 6
;****************************************
;
        CREATE,1;
MARK6   QUEUE,13;
        SEIZE,2:RADIO6;
        DELAY:60;
        RELEASE:RADIO6:NEXT(MARK6);
;
;*************************
;   SUBMODEL FOR RAU 7
;*************************
;
;CHECK THE RAU'S SATURATION FLAG, IF IT IS EQUAL TO
;ONE THEN THIS DEMAND IS AN INCOMING CALL.  THE CALL
;IS DELAYED BY SOME SECONDS, THE RETRY COUNTER IS
;INCREMENTED BY ONE AND THE CALL THEN ENCOUNTERS A
;BRANCH WHICH CHECKS IF THE RETRY IS A THIRD ATTEMPT.
;IF IT IS THEN THE CALL IS DISPOSED OF.  OTHERWISE
;THE CALL IS COUNTED AS AN UNSUCCESSFUL CALL, COUNTED
;AS A RETRY, AND IS THEN ROUTED BACK TO THE BEGINNING
;OF THE SUBMODEL FOR THIS NODE.
;
RAU7    ASSIGN:A(4)=DP(9,1);    ASSIGN LINK TO BE USED
        BRANCH,1:
           IF,X(15).EQ.1,HOLD77:
           ELSE,PASS7;
;
HOLD77     DELAY:EX(13,1);
           ASSIGN:A(6)=A(6)+1;
;
;CHECK TO SEE IF THIS CALL IS A SECOND RETRY, IF IT
;IS THEN COUNTIT AS AN UNSUCCESSFUL CALL, OTHERWISE
;ALLOW IT TO PROCESS ON.
;
           BRANCH,1:
              IF,A(6).GT.1,QUIT:
              ELSE,NXT7;
;
NXT7       COUNT:14;
           COUNT:29:NEXT(RAU7);
;
;CHECK TO SEE IF 5 OR MORE RADIOS ARE IN USE, IF SO
;GO TO PRESATURATION
;
PASS7   BRANCH,1:
           IF,NR(15).GE.5,PRESAT7:
           ELSE,CALLCOM7;
;
```

```
;IN PRESATURATION CHECK CALLS PRECEDENCE, IF
;IMMEDIATE OR FLASH, THE CALL CAN GO THROUGH,
;OTHERWISE CHECK TO SEE IF THE CALL IS
;AN OUTGOING CALL WHEREBY THE PRECEDENCE MAKES
;NO DIFFERENCE SO THE CALL IS ALLOWED TO CONTINUE.
;IF THE CALL IS AN INCOMING CALL THEN
;ROUTE IT TO BE COUNTED AS A RETRY AS DESCRIBED ABOVE.
;
PRESAT7  BRANCH,1:
             IF,A(3).GE.3,CHECK7:
             ELSE,OUTGO7;
;
OUTGO7   BRANCH,1:
             IF,A(7).EQ.2,CHECK7:
             ELSE,HOLD77;
;
;CHECK TO SEE IF THE BEACON BROADCASTING RADIO SHOULD
;BE BUMPED TO MAKE ROOM FOR THE EIGHTH SIMULTANEOUS
;CALL FROM THIS NODE
;
CHECK7   BRANCH,1:
             IF,NR(15).EQ.8,REAFFIL7:
             ELSE,CALLCOM7;
;
;THE CALL IS SERVICED BY ONE OF THE 8 AVAILABLE RADIOS
;AT THIS RAU, AND THE LINK SPECIFIED IN A(4) IS SEIZED.
;
CALLCOM7 QUEUE,7;
         SEIZE,1:RADIO7;
CALL7    QUEUE,28:MARK(5);
         SELECT,UR(1):LNK71:LNK72:LNK73:LNK74:LNK75:LNK76:
         LNK77:LNK78;
LNK71    SEIZE:LINK1,1:NEXT(HOLD7);
LNK72    SEIZE:LINK2,1:NEXT(HOLD7);
LNK73    SEIZE:LINK3,1:NEXT(HOLD7);
LNK74    SEIZE:LINK4,1:NEXT(HOLD7);
LNK75    SEIZE:LINK5,1:NEXT(HOLD7);
LNK76    SEIZE:LINK6,1:NEXT(HOLD7);
LNK77    SEIZE:LINK7,1:NEXT(HOLD7);
LNK78    SEIZE:LINK8,1:NEXT(HOLD7);
HOLD7    DELAY:A(3); HOLD THE RADIO THE TIME OF THE CALL
         RELEASE:RADIO7; RELEASE THE RADIO
         BRANCH,1:
             IF,A(4).EQ.1,RLLNK71:
             IF,A(4).EQ.2,RLLNK72:
             IF,A(4).EQ.3,RLLNK73:
             IF,A(4).EQ.4,RLLNK74:
             IF,A(4).EQ.5,RLLNK75:
             IF,A(4).EQ.6,RLLNK76:
             IF,A(4).EQ.7,RLLNK77:
             ELSE,RLLNK78;
RLLNK71     RELEASE:LINK1,1:NEXT(TAL7);
RLLNK72     RELEASE:LINK2,1:NEXT(TAL7);
RLLNK73     RELEASE:LINK3,1:NEXT(TAL7);
RLLNK74     RELEASE:LINK4,1:NEXT(TAL7);
```

```
RLLNK75   RELEASE:LINK5,1:NEXT(TAL7);
RLLNK76   RELEASE:LINK6,1:NEXT(TAL7);
RLLNK77   RELEASE:LINK7,1:NEXT(TAL7);
RLLNK78   RELEASE:LINK8,1:NEXT(TAL7);
TAL7      TALLY:A(4),INT(5);
;KEEPS TRACK OF THE TIME THE LINK WAS USED
          COUNT:7; COUNT THIS AS A SUCCESSFUL CALL
;
;CHECK IF THE FLAG INDICATING THAT THIS NODE WAS
;SATURATED WAS SET TO ONE, IF IT WAS NOW THERE
;ARE NO LONGER 8 RADIOS IN SERVICE
;AND ONE OF THE RADIOS CAN BROADCAST THE MARKER
;FREQUENCY.  IF THE FLAG WAS NOT SET GO TO LABEL FINISH.
;
          BRANCH,1:
             IF,X(15).EQ.1,UNREAFL7:
             ELSE,FINISH;
;
REAFFIL7 ASSIGN:X(8)=7;  SET THE FLAGS INDICATING THE
;                        NODE IS SATURATED
          ASSIGN:A(9)=7;
          QUEUE,20;
P7        PREEMPT,1:RADIO7,5,OUT7;  BUMP THE MARKER
;                                   SIGNAL FOR A CALL
BUMP7     EVENT:1:NEXT(CALL7);      CALL FORTRAN SUBROUTINE
;EVENT 1 WHICH CAUSES THE REMAINING SUBSCRIBERS TO
;AFFILIATE WITH A NEIGHBORING NODE BROADCASTING A MARKER
;SIGNAL.
;
UNREAFL7 ASSIGN:X(8)=17;  SET THE FLAGS TO INDICATE
;THAT THE NODE IS NO LONGER SATURATED.
          ASSIGN:A(9)=7;
UNBUMP7   EVENT:2:NEXT(FINISH);  CALL SUBROUTINE EVENT 2
;WHICH CAUSES SUBSCRIBERS TO REAFFILIATE WITH THEIR
;ORIGINAL RAU.
;
;****************************************
;SUB MODEL FOR MARKER FREQUENCY FOR RAU 7
;****************************************
;
          CREATE,1;
MARK7     QUEUE,14;
          SEIZE,2:RADIO7;
          DELAY:60;
          RELEASE:RADIO7:NEXT(MARK7);
;
;******************
;      COUNTERS
;******************
;
;THE FOLLOWING COUNTERS ARE ADDRESSED BY EACH RAU
;SUBMODEL.  THEY COUNT THE NUMBER OF TIMES EACH
;MARKER FREQUENCY IS PREEMPTED.
;
OUT1      COUNT:15:NEXT(MARK1);
```

```
OUT2      COUNT:16:NEXT(MARK2);
OUT3      COUNT:17:NEXT(MARK3);
OUT4      COUNT:18:NEXT(MARK4);
OUT5      COUNT:19:NEXT(MARK5);
OUT6      COUNT:20:NEXT(MARK6);
OUT7      COUNT:21:NEXT(MARK7);
;
QUIT      TALLY:9,0:DISPOSE;
;
;THE FOLLOWING ROUTINE COUNTS THE TOTAL SUCCESSFUL
;CALLS IN COUNTER 22.  TALLY 9 IS USED TO COMPUTE
;THE AVERAGE GRADE OF SERVICE.  FOR EVERY SUCCESSFUL
;CALL A ONE IS TALLIED IN TALLY 9.  AT THE QUIT LABEL
;ABOVE EVERY UNSUCCESSFUL CALL HAS A ZERO TALLIED IN
;TALLY 9.  THE TALLY MAINTAINS AN AVERAGE OF
;THE TOTAL SUCCESSFUL CALLS DIVIDED BY THE TOTAL CALL
;ARRIVALS EXCLUSIVE OF RETRYS, WHICH IS THE NETWORK
;GRADE OF SERVICE.
;
FINISH    COUNT:22;
          TALLY:9,1:DISPOSE;
;
END;
```

```
BEGIN;
;*******************************************************
;EXPERIMENTAL FRAME LISTING FOR THE MSRT - RAU SIMULATION
;*******************************************************
PROJECT,MSRTRAU SIMULATION,R.A.PARADISO,3/01/89;
;
DISCRETE,600,9,28;
;
PARAMETERS:1,0.25,1,0.5,2,0.7,3,1.0,4:
           2,3.0:
           3,.2,2,.4,3,.6,4,.72,5,.84,6,.96,7,1.0,8:
           4,.2,1,.4,4,.6,5,.72,2,.84,3,.96,6,1.0,8:
           5,.2,1,.4,4,.6,6,.72,2,.84,3,.96,5,1.0,8:
           6,.2,1,.4,2,.6,3,.8,5,.88,6,.96,7,1.0,8:
           7,.2,2,.4,4,.6,7,.72,1,.84,3,.96,5,1.0,8:
           8,.2,3,.4,4,.6,7,.72,1,.84,2,.96,6,1.0,8:
           9,.2,4,.4,5,.6,6,.72,1,.84,2,.96,3,1.0,8:
          10,.375:
          11,.143,1,.286,2,.429,3,.572,4,.715,5,.858,6,1.0,7:
          12,.5,1,1.0,2:
          13,.25;
;
;SET THE INITIAL NUMBER OF SUBSCRIBERS IN EACH RAU AT 32
;
INITIALIZE,X(1)=32,X(2)=32,X(3)=32,X(4)=32,X(5)=32,X(6)=32,
           X(7)=32;
;
;SET THE NUMBER OF LINK RESOURCES EQUAL TO 12 CHANNELS FOR
;EACH OF THE 8 AVAILABLE LINKS AND THE RADIO RESOURCES EQUAL
;TO 8 AT EACH RAU
;
RESOURCES: 1,LINK1,12:
           2,LINK2,12:
           3,LINK3,12:
           4,LINK4,12:
           5,LINK5,12:
           6,LINK6,12:
           7,LINK7,12:
           8,LINK8,12:
           9,RADIO1,8:
           10,RADIO2,8:
           11,RADIO3,8:
           12,RADIO4,8:
           13,RADIO5,8:
           14,RADIO6,8:
           15,RADIO7,8;
;
;SET UT THE TALLIES DESIRED
;
TALLIES:   1,LINK1 TIME USED:
           2,LINK2 TIME USED:
           3,LINK3 TIME USED:
           4,LINK4 TIME USED:
           5,LINK5 TIME USED:
           6,LINK6 TIME USED:
```

```
              7,LINK7 TIME USED:
              8,LINK8 TIME USED:
              9,GRADE OF SERVICE,61;
;
;SET UP THE COUNTERS DESIRED
;
COUNTERS:     1,SUC. CALL RAU1:
              2,SUC. CALL RAU2:
              3,SUC. CALL RAU3:
              4,SUC. CALL RAU4:
              5,SUC. CALL RAU5:
              6,SUC. CALL RAU6:
              7,SUC. CALL RAU7:
              8,UNSUC. CALL RAU1:
              9,UNSUC. CALL RAU2:
             10,UNSUC. CALL RAU3:
             11,UNSUC. CALL RAU4:
             12,UNSUC. CALL RAU5:
             13,UNSUC. CALL RAU6:
             14,UNSUC. CALL RAU7:
             15,MARKER 1 BUMPED:
             16,MARKER 2 BUMPED:
             17,MARKER 3 BUMPED:
             18,MARKER 4 BUMPED:
             19,MARKER 5 BUMPED:
             20,MARKER 6 BUMPED:
             21,MARKER 7 BUMPED:
             22,TOTAL SUC. CALLS:
             23,RETRY AT RAU1:
             24,RETRY AT RAU2:
             25,RETRY AT RAU3:
             26,RETRY AT RAU4:
             27,RETRY AT RAU5:
             28,RETRY AT RAU6:
             29,RETRY AT RAU7:
             30,TOT CALL ARVALS;
;
;COMPUTE STATISTICS
;
DSTAT:        1,NR(1),LINK1 UTIL:
              2,NR(2),LINK2 UTIL:
              3,NR(3),LINK3 UTIL:
              4,NR(4),LINK4 UTIL:
              5,NR(5),LINK5 UTIL:
              6,NR(6),LINK6 UTIL:
              7,NR(7),LINK7 UTIL:
              8,NR(8),LINK8 UTIL:
              9,NR(9),RADIO1 UTIL:
              10,NR(10),RADIO2 UTIL:
              11,NR(11),RADIO3 UTIL:
              12,NR(12),RADIO4 UTIL:
              13,NR(13),RADIO5 UTIL:
              14,NR(14),RADIO6 UTIL:
              15,NR(15),RADIO7 UTIL:
              16,X(1),RAU1 SUBSCRIBERS:
```

```
                 17,X(2),RAU2 SUBSCRIBERS:
                 18,X(3),RAU3 SUBSCRIBERS:
                 19,X(4),RAU4 SUBSCRIBERS:
                 20,X(5),RAU5 SUBSCRIBERS:
                 21,X(6),RAU6 SUBSCRIBERS:
                 22,X(7),RAU7 SUBSCRIBERS:
                 23,X(9),SATR. LEVEL RAU1:
                 24,X(10),SATR. LEVEL RAU2:
                 25,X(11),SATR. LEVEL RAU3:
                 26,X(12),SATR. LEVEL RAU4:
                 27,X(13),SATR. LEVEL RAU5:
                 28,X(14),SATR. LEVEL RAU6:
                 29,X(15),SATR. LEVEL RAU7:
                 30,X(24),UNAFL. SUBS RAU1:
                 31,X(25),UNAFL. SUBS RAU2:
                 32,X(26),UNAFL. SUBS RAU3:
                 33,X(27),UNAFL. SUBS RAU4:
                 34,X(28),UNAFL. SUBS RAU5:
                 35,X(29),UNAFL. SUBS RAU6:
                 36,X(30),UNAFL. SUBS RAU7:
                 37,X(37),NETWK SAT.LEVEL,60;
;
;RUN THE SIMULATION FOR A SIXTEEN HOUR PERIOD
REPLICATE,1,0,960;
;
END;
```

APPENDIX B

FORTRAN SUBROUTINE PROGRAM LISTING

```
C***********************************************************
C     FORTRAN SUBROUTINES USED IN THE MSRT - RAU SIMULATION
C***********************************************************
C
C*****************************
      SUBROUTINE EVENT(JOB,N)
C*****************************
C
      COMMON/SIM/D(50),DL(50),S(50),SL(50),X(50),DTNOW,TNOW,
     +TFIN,J,NRUN
      COMMON/SUB/I,K,M1(10,7),M2(9,7),IB,NA,N2,N3,I1,I4,IA(6),
     +II,L1,L2,L5,L6,S1,KA
C
C     DIRECT THE SUBROUTINE CALL TO THE APPROPRIATE ACTION
C
      IF(N.EQ.2) GO TO 50
C
C******************************
C     REAFFILIATION ACTION
C******************************
C
C     DEPENDING ON THE VALUE OF ATTRIBUTE A(9), THE VARIABLE
C     I WILL BE SET TO THE VALUE OF THE RAU THAT JUST WENT
C     INTO SATURATION.
C
      I=A(JOB,9)
C     THE FLAG FOR RAU I IS SET TO ONE INDICATING
C     THAT THE NODE IS NOW SATURATED.
      M1(8,I)=1
C     SET THE SIMAN VARIABLE FLAG SHOWING THE NODE IS SATURATED
      X(I+8)=1
C     THE COUNTER INDICATING HOW MANY TIMES THE NODE WAS
C     SATURATED IS INCREMENTED BY ONE.
      M1(9,I)=M1(9,I)+1
      IB=7
C
C     THE SIMAN VARIABLE X(37) IS INCREMENTED BY 1/7 TO
C     SHOW  THAT ONE SEVENTH OF THE NETWORK IS IN  SATURATION.
C     THIS VARIABLE WILL BE USED TO PROVIDE TIME PERSISTANT
C     STATISTICS REGARDING THE NETWORK SATURATION LEVEL.
C
      X(37)=X(37)+0.142857142
C
C     THE FOLLOWING DO LOOP DETERMINES THE NUMBER OF
C     SUBSCRIBERS THAT MUST REAFFILIATE WITH NEIGHBORING
C     NODES AND SETS THAT VALUE EQUAL TO THE VARIABLE NA.
C     IT THEN SETS THE NUMBER OF SUBSCRIBERS  CURRENTLY
C     AFFILIATED WITH THE NOW SATURATED NODE EQUAL TO EIGHT
C     AND THEN CALLS SUBROUTINE SUB1.
      DO 10 KA=1,IB
```

```
          IF(M1(KA,I).EQ.2) THEN
             NA=M2(I,I)-8
             M2(I,I)=8
             CALL SUB1(KA,NA)
          ELSE IF(M1(KA,I).EQ.1) THEN
             NA=M2(KA,I)
              IF(NA.NE.0) THEN
                 M2(KA,I)=0
                 CALL SUB1(KA,NA)
              ENDIF
          ENDIF
10      CONTINUE
        DO 25 L1=1,IB
          X(L1)=0
        DO 25 L2=1,IB
          X(L1)=X(L1)+M2(L2,L1)
          M2(8,L1)=X(L1)
25      CONTINUE
        X(49)=0
        DO 30 L1=1,IB
          X(49)=X(49)+M2(8,L1)
30      CONTINUE
C
C       THE FOLLOWING ACTIONS CAUSE THE VARIABLES X(31-36) TO BE
C       SET EQUAL TO THE PROPORTION OF SUBSCRIBERS AT EACH RAU
C       DIVIDED BY THE TOTAL NUMBER OF SUBSCRIBERS.  THIS IS SO
C       CALL DEMANDS CAN BE ROUTED TO THE RAUS ACCORDINGLY.
C
        X(31)=X(1)/X(49)
        X(32)=(X(1)+X(2))/X(49)
        X(33)=(X(1)+X(2)+X(3))/X(49)
        X(34)=(X(1)+X(2)+X(3)+X(4))/X(49)
        X(35)=(X(1)+X(2)+X(3)+X(4)+X(5))/X(49)
        X(36)=(X(1)+X(2)+X(3)+X(4)+X(5)+X(6))/X(49)
C
C       THE FOLLOWING ACTIONS CHANGE THE PARAMETER VALUE IN THE
C       SIMAN EXPERIMENTAL FRAME TO CORRESPOND TO THE PROPORTION
C       OF CALL DEMANDS EACH NODE RECEIVES.
C
        CALL SETP(11,1,X(31))
        CALL SETP(11,3,X(32))
        CALL SETP(11,5,X(33))
        CALL SETP(11,7,X(34))
        CALL SETP(11,9,X(35))
        CALL SETP(11,11,X(36))
C
        RETURN

C
C************************************
C   UN REAFFILIATE SUBSCRIBERS ACTION
C************************************
C
C       DEPENDING ON THE VALUE OF ATTRIBUTE A(9), THE RAU THAT IS
C       TO UNREAFFILIATE ITS SUBSCRIBERS WILL BE SET THE VARIABLE
```

```
I
C
C      I=THE NODE THAT JUST UNSATURATED
C
50     I=A(JOB,9)
       IB=7
C      SET THE SATURATION FLAG IN THE MATRIX SHOWING THE NODE IS
C      NOW UNSATURATED
C
       M1(8,I)=0
C      SET  THE  SIMAN  VARIABLE FLAG SHOWING  THE  NODE  IS
C      UNSATURATED
       X(I+8)=0
       S1=0
C
C       THE  SIMAN VARIABLE X(37) IS DECREMENTED BY 1/7 TO  SHOW
C       THAT ONE SEVENTH OF THE NETWORK IS OUT OF SATURATION.
C       THIS VARIABLE  WILL  BE  USED  TO  PROVIDE  TIME
C       PERSISTANT STATISTICS REGARDING THE NETWORK SATURATION
C       LEVEL.
C
       X(37)=X(37)-0.142857142
C
C      CHECK THE FLAG SHOWING THAT THERE ARE TOTALLY
C      UNAFFILIATED SUBSCRIBERS FROM THIS RAU. IF IT IS ONE
C      THEN AFFILIATE THOSE SUBSCRIBERS WITH THEIR ORIGINAL
C      NODE AND RESET THE UNAFFILIATE FLAG AND THE SATURATION
C      FLAG.
       IF (M1(10,I).EQ.1) THEN
         M2(I,I)=M2(I,I)+M2(9,I)
         M2(9,I)=0
         M1(10,I)=0
         X(I+23)=0
       ENDIF
       DO 35 KA=1,IB
         IF(M1(I,KA).EQ.1) THEN
           S1=S1+M2(I,KA)
           M2(I,KA)=0
         ENDIF
35     CONTINUE
       DO 63 KA=1,IB
         IF((M1(I,KA).EQ.1).AND.(M1(10,KA).EQ.1)) THEN
           M2(KA,I)=M2(KA,I)+M2(9,KA)
           M1(10,KA)=0
           M2(9,KA)=0
           X(KA+23)=0
         ENDIF
63     CONTINUE
       M2(I,I)=M2(I,I)+S1
       DO 27 L5=1,IB
         X(L5)=0
       DO 27 L6=1,IB
         X(L5)=X(L5)+M2(L6,L5)
         M2(8,L5)=X(L5)
27     CONTINUE
```

```
      X(48)=0
      DO 31 L1=1,IB
        X(48)=X(48)+M2(8,L1)
31    CONTINUE
C
C     THE FOLLOWING ACTIONS CAUSE THE VARIABLES X(31-36) TO BE
C     SET EQUAL TO THE PROPORTION OF SUBSCRIBERS AT EACH RAU
C     DIVIDED BY THE TOTAL NUMBER OF SUBSCRIBERS.  THIS IS SO
C     CALL DEMANDS CAN BE ROUTED TO THE RAUS ACCORDINGLY.
C
      X(31)=X(1)/X(48)
      X(32)=(X(1)+X(2))/X(48)
      X(33)=(X(1)+X(2)+X(3))/X(48)
      X(34)=(X(1)+X(2)+X(3)+X(4))/X(48)
      X(35)=(X(1)+X(2)+X(3)+X(4)+X(5))/X(48)
      X(36)=(X(1)+X(2)+X(3)+X(4)+X(5)+X(6))/X(48)
C
C     THE FOLLOWING ACTIONS CHANGE THE PARAMETER VALUE IN THE
C     SIMAN EXPERIMENTAL FRAME TO CORRESPOND TO THE PROPORTION
C     OF CALL DEMANDS EACH NODE RECEIVES.
C
      CALL SETP(11,1,X(31))
      CALL SETP(11,3,X(32))
      CALL SETP(11,5,X(33))
      CALL SETP(11,7,X(34))
      CALL SETP(11,9,X(35))
      CALL SETP(11,11,X(36))
C
      RETURN
      END
C
C ************************
      SUBROUTINE SUB1
C ************************
C
      COMMON/SIM/D(50),DL(50),S(50),SL(50),X(50),DTNOW,TNOW,
     +TFIN,J,NRUN
      COMMON/SUB/I,K,M1(10,7),M2(9,7),IB,NA,N2,N3,I1,I4,IA(6),
     +II,L1,L2,L5,L6,S1,KA
C
      IB=7
      I1=0
      DO 1 I4=1,6
1     IA(I4)=0
      DO 5 K=1,IB
          IF(M1(K,KA).EQ.1) THEN
            IF(M1(8,K).EQ.0) THEN
               I1=I1+1
               IA(I1)=K
            ENDIF
          ENDIF
5     CONTINUE
      IF (I1.EQ.0) THEN
        M1(10,KA)=1
        M2(9,KA)=M2(9,KA)+NA
```

```
            X(KA+23)=M2(9,KA)
          ELSE
            N2=NA/I1
            N3=NA-(N2*I1)
            DO 15 II=1,I1
              M2(KA,IA(II))=M2(KA,IA(II))+N2
15          CONTINUE
            IF(N3.NE.0) THEN
              DO 20 II=1,N3
                M2(KA,IA(II))=M2(KA,IA(II))+1
20          CONTINUE
            ENDIF
          ENDIF
          RETURN
          END
C
C**********************
          SUBROUTINE PRIME
C**********************
C
C     THIS SUBROUTINE SETS THE INITIAL VALUES OF THE VARIABLES
C     AND COUNTERS USED ONLY IN THE FORTRAN SUBROUTINES
C
       COMMON/SIM/D(50),DL(50),S(50),SL(50),X(50),DTNOW,TNOW,
      +TFIN,J,NRUN
       COMMON/SUB/I,K,M1(10,7),M2(9,7),IB,NA,N2,N3,I1,I4,IA(6),
      +II,L1,L2,L5,L6,S1,KA
C
       IB=7
       I=0
       K=0
       OPEN (UNIT=24,FILE='NUM.DAT',STATUS='OLD')
       DO 55 I=1,10
       READ(24,56)(M1(I,KA),KA=1,7)
 56    FORMAT(7I5)
 55    CONTINUE
         DO 61 I=1,7
         DO 61 KA=1,7
           IF(I.EQ.KA) THEN
             M2(I,KA)=32
           ELSE
             M2(I,KA)=0
           ENDIF
 61    CONTINUE
       DO 62 KA=1,IB
         M2(8,KA)=0
         M2(9,KA)=0
 62    CONTINUE
       RETURN
       END
C
C***********************
       FUNCTION UR(JOB,N)
C***********************
       COMMON/SIM/D(50),DL(50),S(50),SL(50),X(50),DTNOW,TNOW,
```

```
     +TFIN,J,NRUN
C
C     SET USER RULE TO CHOOSE WHICH LINK TO SEIZE
C
      UR=A(JOB,4)
      RETURN
      END
```

APPENDIX C

EXAMPLE SIMAN SUMMARY REPORT

SIMAN Summary Report

Run Number 2 of 18

Project: NSRTRAU SIMULATION
Analyst: R.A.PARADISO
Date : 3/ 1/1989

Run ended at time .9600E+03

Run Parameters: Mean Time Between Call Arrivals - 0.25 minutes
Mean Call Holding Time - 5.0 minutes

Tally Variables

Number	Identifier	Average	Standard Deviation	Minimum Value	Maximum Value	Number of Obs.
1	LINK1 TIME USED	6.12604	5.60279	.08551	31.22493	200
2	LINK2 TIME USED	5.34308	4.30114	.05771	22.70551	217
3	LINK3 TIME USED	5.64838	5.46734	.00622	31.78265	229
4	LINK4 TIME USED	5.69882	4.63556	.02365	27.98925	226
5	LINK5 TIME USED	5.99494	5.23545	.00393	30.87787	227
6	LINK6 TIME USED	6.31570	5.45502	.10526	32.60095	149
7	LINK7 TIME USED	5.98226	5.93516	.03015	34.08362	136
8	LINK8 TIME USED	5.88710	5.02641	.00298	23.30389	65
9	GRADE OF SERVICE	.36572	.48169	.00000	1.00000	3962

Discrete Change Variables

Number	Identifier	Average	Standard Deviation	Minimum Value	Maximum Value	Time Period
1	LINK1 UTIL	6.99188	2.27855	.00000	12.00000	960.00
2	LINK2 UTIL	7.53901	2.40586	.00000	12.00000	960.00
3	LINK3 UTIL	7.55258	2.37417	.00000	12.00000	960.00
4	LINK4 UTIL	6.80618	2.35042	.00000	12.00000	960.00
5	LINK5 UTIL	7.96636	2.41606	.00000	12.00000	960.00
6	LINK6 UTIL	6.03546	1.61014	.00000	9.00000	960.00

Number	Identifier	Average	Standard Deviation	Minimum Value	Maximum Value	Time Period
7	LINK7 UTIL	5.29853	1.14231	.00000	10.00000	960.00
8	LINK8 UTIL	1.21215	.69020	.00000	4.00000	960.00
9	RADIO1 UTIL	7.28784	1.62326	.00000	8.00000	960.00
10	RADIO2 UTIL	7.31522	1.64843	.00000	8.00000	960.00
11	RADIO3 UTIL	7.24800	1.77080	.00000	8.00000	960.00
12	RADIO4 UTIL	7.42178	1.56471	.00000	8.00000	960.00
13	RADIO5 UTIL	7.26965	1.72102	.00000	8.00000	960.00
14	RADIO6 UTIL	7.72570	.97136	.00000	8.00000	960.00
15	RADIO7 UTIL	7.21480	1.84649	.00000	8.00000	960.00
16	RAU1 SUBSCRIBERS	21.15741	24.63499	8.00000	104.00000	960.00
17	RAU2 SUBSCRIBERS	21.34894	24.59750	8.00000	104.00000	960.00
18	RAU3 SUBSCRIBERS	20.81049	23.49705	8.00000	104.00000	960.00
19	RAU4 SUBSCRIBERS	24.40963	38.59141	8.00000	176.00000	960.00
20	RAU5 SUBSCRIBERS	21.40232	24.82238	8.00000	104.00000	960.00
21	RAU6 SUBSCRIBERS	19.49462	24.30433	8.00000	104.00000	960.00
22	RAU7 SUBSCRIBERS	21.23051	25.02142	8.00000	104.00000	960.00
23	SATR. LEVEL RAU1	.68922	.46281	.00000	1.00000	960.00
24	SATR. LEVEL RAU2	.68428	.46480	.00000	1.00000	960.00
25	SATR. LEVEL RAU3	.68989	.46254	.00000	1.00000	960.00
26	SATR. LEVEL RAU4	.73273	.44254	.00000	1.00000	960.00
27	SATR. LEVEL RAU5	.68328	.46520	.00000	1.00000	960.00
28	SATR. LEVEL RAU6	.74177	.43766	.00000	1.00000	960.00
29	SATR. LEVEL RAU7	.69801	.45912	.00000	1.00000	960.00
30	UNAFL. SUBS RAU1	11.00345	11.95855	.00000	24.00000	960.00
31	UNAFL. SUBS RAU2	10.90315	11.94976	.00000	24.00000	960.00
32	UNAFL. SUBS RAU3	11.11835	11.96757	.00000	24.00000	960.00
33	UNAFL. SUBS RAU4	7.89083	11.27451	.00000	24.00000	960.00
34	UNAFL. SUBS RAU5	10.96196	11.95502	.00000	24.00000	960.00
35	UNAFL. SUBS RAU6	11.30388	11.97979	.00000	24.00000	960.00
36	UNAFL. SUBS RAU7	10.96444	11.95523	.00000	24.00000	960.00
37	NETWK SAT.LEVEL	.70274	.34230	.00000	1.00000	960.00

Counters

Number	Identifier	Count	Limit
1	SUC. CALL RAU1	231	Infinite
2	SUC. CALL RAU2	204	Infinite
3	SUC. CALL RAU3	198	Infinite
4	SUC. CALL RAU4	203	Infinite
5	SUC. CALL RAU5	236	Infinite
6	SUC. CALL RAU6	161	Infinite
7	SUC. CALL RAU7	216	Infinite
8	UNSUC. CALL RAU1	364	Infinite
9	UNSUC. CALL RAU2	386	Infinite
10	UNSUC. CALL RAU3	368	Infinite
11	UNSUC. CALL RAU4	396	Infinite
12	UNSUC. CALL RAU5	345	Infinite

Number	Identifier	Count	Limit
13	UNSUC. CALL RAU6	339	Infinite
14	UNSUC. CALL RAU7	376	Infinite
15	MARKER 1 BUMPED	129	Infinite
16	MARKER 2 BUMPED	111	Infinite
17	MARKER 3 BUMPED	112	Infinite
18	MARKER 4 BUMPED	127	Infinite
19	MARKER 5 BUMPED	132	Infinite
20	MARKER 6 BUMPED	116	Infinite
21	MARKER 7 BUMPED	123	Infinite
22	TOTAL SUC. CALLS	1449	Infinite
23	RETRY AT RAU1	364	Infinite
24	RETRY AT RAU2	386	Infinite
25	RETRY AT RAU3	368	Infinite
26	RETRY AT RAU4	396	Infinite
27	RETRY AT RAU5	345	Infinite
28	RETRY AT RAU6	339	Infinite
29	RETRY AT RAU7	376	Infinite
30	TOT CALL ARVALS	4032	Infinite

Run Time : 14 Minute(s) and 50 Second(s)

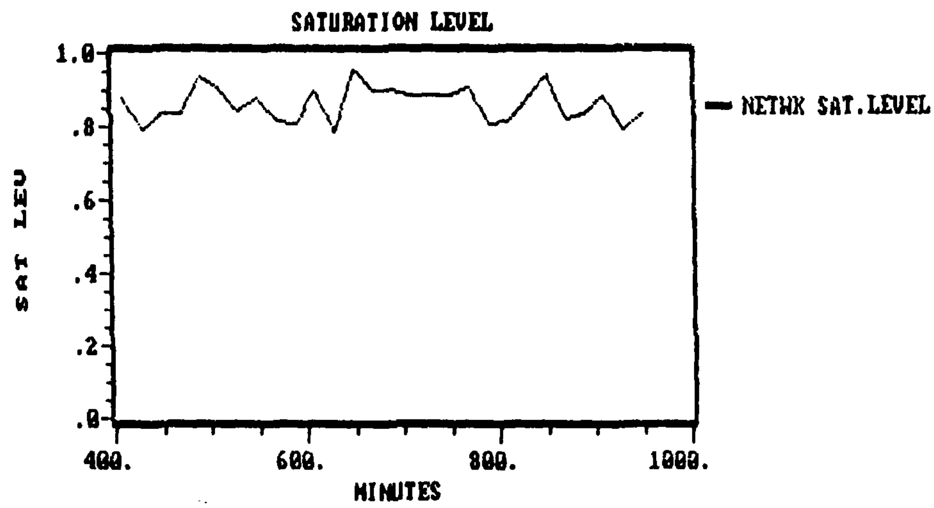
Stop - Program terminated.

APPENDIX D

EXAMPLE PLOT, CONFIDENCE INTERVAL, AND BATCHING

FILTER SUMMARY : SATURATION LEVEL

INITIAL TIME TRUNCATED	400.0
TIME SPANNED PER BATCH	20.00
NUMBER OF BATCHES	28
TRAILING TIME TRUNCATED	.0000
EST. OF COV. BETWEEN BATCHES	-1.1233E-02



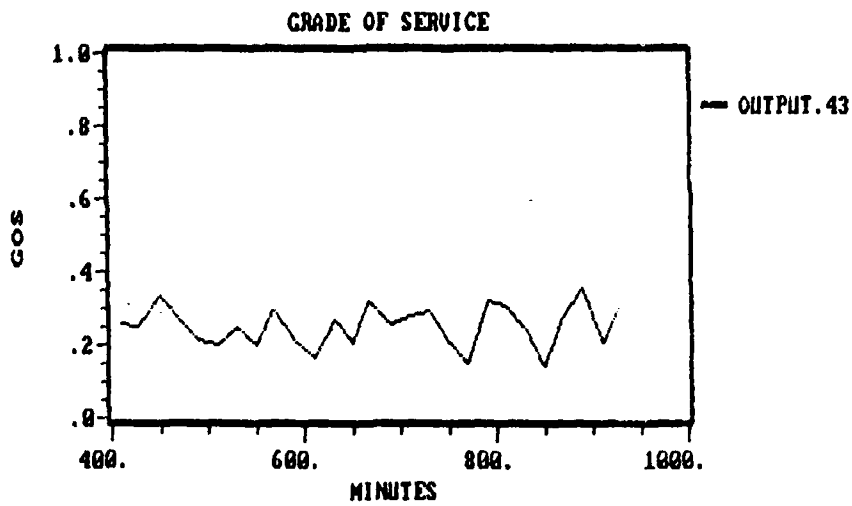
OBSERVATION INTERVALS : SATURATION LEVEL

	.784	.843	.862	.881	.960
NETWK SAT.LEVEL	<	[	X	]	>

< = MINIMUM [= LOWER 95% CL X = AVERAGE] = UPPER 95% CL > = MAXIMUM

FILTER SUMMARY : GRADE OF SERVICE

INITIAL TIME TRUNCATED	400.0	
TIME SPANNED PER BATCH	20.00	
NUMBER OF BATCHES		27
TRAILING TIME TRUNCATED	19.81	
EST. OF COV. BETWEEN BATCHES	-.1027	



OBSERVATION INTERVALS : GRADE OF SERVICE

OUTPUT.43	(.142	[.230	X .252	] .275	) .357

(= MINIMUM [= LOWER 95% CL X = AVERAGE] = UPPER 95% CL) = MAXIMUM

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